

THE LIMESTONES OF MARYLAND

WITH SPECIAL REFERENCE TO THEIR USE IN THE
MANUFACTURE OF

LIME AND CEMENT

BY

EDWARD B. MATHEWS AND JOHN SHARSHALL GRASTY

INCLUDING

A dissertation submitted to the Board of University Studies of the
Johns Hopkins University in conformity with the requirements for
the degree of Doctor of Philosophy, May, 1908

BY

JOHN SHARSHALL GRASTY

BALTIMORE, MARCH, 1910

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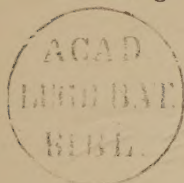
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PART III

REPORT ON

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INTRODUCTION.

DISTRIBUTION.—Limestone is found widely distributed throughout the Piedmont and Appalachian regions of Maryland, the most important occurrences being in Baltimore, Carroll, Frederick, Washington, and Allegany counties. The floors of the great Frederick and Hagerstown valleys are composed of this rock while many of the smaller valleys, both in the Piedmont and Appalachian regions likewise, are underlain by this material. Marl, which at times has the composition of an impure limestone without the induration which characterizes that rock, is found in several localities in the southern and eastern counties, but nowhere attains sufficient importance to be employed for more than local uses. It is found chiefly in Queen Anne's, Talbot, Calvert, St. Mary's, and Prince George's counties.

AGE.—The Maryland limestones vary in age from those that have been assigned to the pre-Cambrian to those of the Carboniferous; the most important being found in the Ordovician, Silurian, and Devonian. The shell marl deposits are chiefly Tertiary, the most important being of Miocene Age.

ORIGIN.—Limestone may be formed either as the result of chemical precipitation from solution or through the accumulation of the shells of organisms that secrete a calcareous test. Most limestones are of organic

origin and have been formed under water, being laid down in the sea at varying depths and at different distances from the shore. Those in Maryland are of marine origin, having been laid down at moderate depths.

Limestones vary both in chemical composition and in physical appearance, the latter often being a criterion of the former. These differences in composition and physical appearance may be due either to differences in the conditions of deposition or to subsequent causes, as for instance, when a limestone from the application of the metamorphic forces, heat and pressure, is changed to a marble. Chemically, the two rocks may be identical, but in one the calcium carbonate is more or less amorphous or perhaps subcrystalline, while in the marble the calcium carbonate is distinctly crystalline, occurring in the form of crystals of calcite in a matrix of calcareous cement. Even more noticeable are the effects due to differences in chemical composition. A limestone deposited under shallow-water conditions and contaminated by land-derived materials is very different both in appearance and in composition from the limestone formed farther off-shore where the water is clearer and deep, and the contaminating impurities such as the suspended material of a muddy sea are probably almost if not entirely absent. In the first case a shaly or argillaceous limestone is formed, while obviously in the latter instance a purer limestone results that is different from the former chemically as well as physically.

COMPOSITION.—The chief constituent of a limestone is calcium carbonate. An absolutely pure limestone contains 56 per cent. CaO (lime) and 44 per cent. CO_2 (carbon dioxide), and its chemical composition is expressed by the formula CaCO_3 (calcium carbonate). Most limestones are contaminated, however, by the presence of other constituents such as magnesia, silica, iron, and alumina; and though there occur workable deposits of very pure limestone whose composition closely approximates that of the ideal as expressed by the formula just given, they are very rare, and because of their scarcity, when well situated for commercial use, are each year becoming increasingly valuable, chiefly because of the growing demand and the necessity of their use in certain metallurgical processes and for other purposes where the purity of the limestone is the

chief essential. It must not be inferred, however, that only the pure limestones are valuable. Often the constituents that cause their impurities give the impure limestones a value for special use, as, for instance, the argillaceous impurities of some of the limestones give them a special value when used in the manufacture of cement. Magnesia, the bane of the Portland cement manufacturer, is one of the chief impurities found in limestones of nearly all geological horizons, but aside from a few notable exceptions, especially is this true of the older limestones. When the magnesia approximates to 21.73 per cent. and the lime 30.44 per cent., with 47.83 CO_2 , the stone so composed is known as a dolomitic. The presence of the magnesium carbonate, though an impurity, unaccompanied by appreciable quantities of the impurities, silica and alumina, renders limestone so constituted adapted for fluxing purposes. It must be evident, therefore, that the value of a limestone may not depend altogether on its purity, but may be equally as valuable because of the lack of it. It is not customary to describe the rock as a limestone when the magnesia is over 21 per cent., or when the sum of the silica, alumina, and iron is more than 36 per cent. The former would be called a dolomite and the latter a calcareous shale.

VARIETIES.—Limestones differ widely in color, texture, and chemical composition. In color limestones range all the way from white to black, depending upon differences in texture and composition. The so-called amorphous limestones generally appear light gray to bluish-gray, weathering light gray to dove-colored and less commonly brown. With increasing crystallinity the color becomes brighter and often white. Crystalline varieties occur which are variegated in color due to microscopic coloring matter or to the presence of colored minerals resulting from the crystallization of original impurities. The color may be uniformly distributed throughout the mass, arranged in definite bands, or disseminated irregularly. In texture they may be massive or laminated, clearly crystalline or apparently amorphous. In chemical composition they may be pure, highly magnesian and dolomitic, or argillaceous, due to clayey impurities with wide ranges in the content of iron, silica and alumina. Marked differences occur not only in the respects just mentioned, but also in the

degree of hardness and in the manner of weathering and fracture. According to the various characteristics, limestones may be described as argillaceous, silicious, bituminous, magnesian; massive, flaggy, or oolitic; chalky, shelly, or coralline. Moreover, a limestone may range, depending on the absence or the degree of metamorphism, from an amorphous limestone to one highly and coarsely crystalline, and in the latter event is properly termed a marble. Many coarsely crystalline limestones, however, are not referred to as marbles because of their not being adapted to purposes for which marble is commonly used, though in a scientific sense they may be true marbles.

USES OF LIMESTONE.

Limestone has a wide range of uses and is easily the most thoroughly exploited of all the sedimentary rocks. Besides yielding the most fertile soils it furnishes the basis of a number of extremely important industries, notably those of cement and lime. Millions of tons are quarried and used in the metallurgy of iron while thousands of tons are also consumed annually by the lead- and copper-smelting industries. As is well known, limestone is extensively employed and much in demand as a building stone and used as a road metal and as ballast and in concrete work, and for a large number of miscellaneous purposes less important which it is unnecessary to enumerate here. The four major uses of limestone are:

1. Building stone.
2. Crushed stone.
3. Metallurgical uses.
4. Limes and cements.

These uses will be taken up and discussed in the order in which they are mentioned.

BUILDING STONE.*

The chief limestones quarried in Maryland and shipped for building stone are the white crystalline varieties; in other words the limestone

* The Building and Decorative Stones of Maryland. Md. Geol. Survey, Vol. II. Pt. II.

found in the eastern and western Piedmont which have been metamorphosed to marbles. The blue and gray Paleozoic limestones that occupy the Hagerstown and Frederick valleys are quarried for local use, but there is no quarry in operation either in the Hagerstown or the Frederick valleys making it a business to furnish these blue-gray limestones for building purposes alone. Since these limestones at certain horizons furnish stone of excellent quality for structural work it is surprising that they are not more widely used for building purposes. A marble resulting from the local metamorphism of the Tomstown formation of the Shenandoah group has, however, been quarried extensively near Eakles Mills, Washington County. The blue and gray limestones are also widely used for minor building purposes, such as trimming, door sills and foundations, although it is noteworthy that few buildings either in Hagerstown, Frederick, or the surrounding towns have been built exclusively of limestone during later years. In the area between North Mountain and the western boundary of the State Paleozoic limestone formations of later geological age occur, namely, the Cayuga, the Helderberg, and the Greenbrier, but none of these has more than a very limited use as a source of building stone. Of the limestone formations mentioned the Helderberg is the only one which offers reasonable grounds for expecting good building material within its limits. The upper massive beds of the Helderberg, which outcrop in five or six small bodies along the Potomac from Hancock to Cumberland, and form a continuous belt from the latter point to Keyser, West Virginia, afford every indication that satisfactory building stone may be obtained. Little if any work has been done in this formation because there has been no local demand.

CRUSHED STONE.

Limestone is sold in the form of crushed stone to be used as road metal, ballast, and for concrete work. The size of the fragment in each case will depend upon the use for which it is employed. The statistics gathered by the Maryland Geological Survey, in conjunction with the United States Geological Survey, show that limestone sold as crushed stone in

Maryland has a much greater value as regards the annual production than any other crude form in which it is marketed. All three types as enumerated above are obtained from crushing the stone as delivered from the quarry either in Austin or Gates crushers or other suitable machinery, then passing it for assortment into sizes through inclined rotary screens. The "screenings" or smallest sizes are being further pulverized by certain operators in various parts of the country to meet a growing demand for ground limestone for use as a soil amendent.

ROAD METAL.*—The limestone for road metal should possess high-cementing power and high resistance to wear. The first property indicates the consolidation of surface dust after rains and a satisfactory cementation of the smaller fragments of the upper course of the road. The high-cementing power usually possessed by limestones offsets in great measure their lower coefficient of wear when compared with trap and other road metals. Crushed limestone for road work is usually assumed to have good cementing values without special testing, but the coefficient of wear must not be less than 12, the cementing power increasing with the purity of the limestone, the wearing ability with an increase of silica.

Most of the limestones in the State are locally serviceable for road metal, but material for high-class construction is more or less limited.

BALLAST.—Crushed limestone is used extensively for ballast in railroad construction because of the angular forms into which the fragments break and the freedom from serious breaking when tamped under the sleepers. Heretofore limestone has been regarded as one of the most satisfactory and economical ballast materials, but with the increase in the weight of rolling stock and the severe demands on the roadbed there has developed the beginning of a demand for stone of higher crushing strength, even if more expensive. This change in demand may lead to the utilization of highly silicious limestone and calcareous sandstone which hitherto have been practically worthless.

CONCRETE.—Stone crushed for use in concrete should be free from large amounts of dust and not too closely screened to uniform size in

* Md. Geol. Survey, Vol. III, pp. 315-330; Vol. IV, pp. 124-133.

the smaller sizes since experiments have shown that the strongest cement mortars are those in which there is the greatest density due to the close packing of different sized fragments which leaves the lowest percentage of voids or cavities. It should be borne in mind that the strength of the stone has an equal if not greater influence on concretes for certain uses, but the relative influence of the size, shape, and strength of the stone fragments has not been finally determined.

GROUND LIMESTONE.—Inasmuch as this ground limestone may be applied at any season of the year, and is said to yield excellent results when ground to a fineness of 60 to 70 mesh, there are those that hold the opinion that it is destined to be largely used as a substitute for burnt lime for agricultural purposes.

The liming of the soils with burnt lime has long been known to effect a "sweetening" of soils which have become "sour." The recent work on the part of agriculturalists and soil bacteriologists has shown that the so-called sour condition of the soil, resulting in a decrease in the second crop of a given cereal, is due more to the toxic condition of the soil through secretions of the vegetation than to an actual lack of plant food. It was also formerly supposed that the liming of the soils not only neutralized the acidity of the soil, but furnished the plant food. When lime (CaOH_2) is added to the soil it gradually changes under the action of the atmosphere and moisture of the soil to carbonate of lime which to some extent is converted through excess of carbon dioxide to soluble bicarbonate or acid carbonate of lime. The use of ground limestone is based upon the assumption that since it is carbonate of lime it will prove as satisfactory as agricultural lime provided the two are of the same degree of fineness. It is a well-known fact that the chemical activity varies with the fineness of the grain on account of the relatively large surface of the individual particles as compared with their mass. The problem for the manufacturer is to establish a balance between the decrease of efficiency due to coarseness of grain and the increase in cost due to excessively fine grinding.

Crushed limestone, or better ground limestone, is now used in enormous quantities in the manufacture of calcium nitrate for use as a ferti-

lizer. The possibility of making a cheap calcium nitrate by treating either calcium carbonate or lime with nitric acid depends upon the cost of the latter reagent. By the introduction of new electrical processes the reduction of cost of nitric acid has been sufficient to render the profitable manufacture of calcium nitrate feasible.

Ground limestone is also used for neutralizing the acidic condition of dyed textiles and in the manufacture of carbon dioxide by the treatment of limestone with acid.

METALLURGICAL USES.

The uses of limestone, including in that term also the dolomites and dolomitic limestones, will depend in general upon its chemical composition, and more particularly upon its freedom from siliceous impurities. The more important uses in the approximate order of purity of stone required are as follows:

1. Glass-making.
2. Furnace linings.
3. Flux in blast furnaces.
4. Flux in basic open hearth steel furnaces.
5. Cement manufacture

Of these uses only 2, 3, and 4 can properly be termed metallurgical uses.

Glass-Making.

Limestone enters as an essential element into the manufacture of glass. In plate glass it equals about one-quarter by weight of the sand in the batch, and in window glass about two-fifths, while in green-bottle glass the proportion by weight compared with the sand is about one-third. The other essential raw materials that enter into mixtures for manufacturing glass are salt cake (Na_2SO_4) and soda ash (Na_2CO_3). Carbon (C), arsenic (As_2O_3), potash (K_2CO_3), and red lead (2Pb-O , PbO_2), are also used in small amounts. Sand constitutes 52 to 65 per cent. of the mixture of raw materials. After this mixture has been melted and carbon dioxide, sulphur dioxide, and other

volatile compounds have been driven off the finished product contains from 60 to 75 per cent. of silica.

Limestone used in glass-making should contain very little ferric oxide and very little magnesia. The former should not exceed .5 to .6 per cent.—the less the better, since the effect of iron in greater amounts than .5 to .6 per cent. is injurious because it detracts from the brilliancy, clearness, and transparency of the finished product. Magnesia is an undesirable constituent, for with it present in the mixture of raw materials more heat is required to produce fusion and form the silicates of sodium, potash, calcium, etc., of which glass is composed, than would otherwise be necessary.

The following analyses give the composition of limestones actually used in glass manufacture. The analyses of limestone is followed by an analysis showing the composition of a typical good glass-sand. A comparison of these limestone analyses with those of some of the limestone material near Union Bridge, and with certain of the limestone occurrences in the eastern Piedmont and elsewhere in the State, shows that limestones of a correct composition for glass-making may be had in Maryland at a number of different localities.

ANALYSES OF LIMESTONE AND SAND USED IN GLASS-MAKING.*

	Limestone.				Sand.
	1	2	3	4	5
Silica (SiO_2)†	8.87	1.86	1.01	1.01	98.94
Alumina (Al_2O_3)	....	....	1.10	.02	.30
Iron (Fe_2O_3)	.59	....	.20	.16‡	.0036
Magnesia (MgO)	.00	.09	....	.72	Tr.
Lime (CaO)	50.53	54.86	54.73	54.45	.40
CO_2	39.70	42.89	42.99	43.55	.23

1. Meramec Quarry Co., Wickes, Mo.
2. Meramec Quarry Co., Wickes, Mo.
3. Armstrong Quarry, Alton, Ill.
4. Pennsylvania., Cf. Mineral Industry, 1899, p. 240.
5. Analysis of Glass-Sand used by Pittsburg Plate Glass Co.

* Burchard, E. F., U. S. G. S. Bull., 285, p. 458.

† Including silicates.

‡ FeCO_3 .

Furnace Linings.

Dolomite and dolomitic limestone is much used as a material for lining basic open-hearth furnaces. The tonnage required for this purpose is, of course, comparatively small, but nevertheless, the use is an important one and requires a stone of high quality.

A brief description of the method of making up these linings seems necessary here. The substructure of the furnace having been built up of common red brick, a permanent lining of basic brick, usually magnesite brick, is built in to a thickness of from 2 to 3 feet. On this is then tamped a working lining of crushed basic material, sometimes magnesite, but now generally dolomite or a mixture of the two. In the older practice it was considered necessary to first calcine the crushed material to drive off the carbon dioxide; it was then mixed with a small percentage of tar or molasses and tamped into place to a thickness of 1 or 2 feet. At present the preliminary calcination is quite generally omitted, satisfactory results being obtained by calcination in place of the raw material mixed with the proper proportion of binder.

From a purely technical standpoint the ideal material for both permanent and working linings is magnesite, and only the excessive cost of this prevents its more extensive employment. While magnesite is known to occur at numerous points in this country, it is only produced commercially in California, and by far the greater proportion of our supply is imported from Greece and Austria. Dolomite, on the other hand, is found in great abundance and of great purity in this country, and hence has largely superseded the more expensive magnesite.

The essential properties of a satisfactory open-hearth furnace lining may be stated as follows:

1. It must be refractory at the highest temperature of the furnace.
2. It must be resistant to the corrosive action of slag and metal.
3. It must not slack or otherwise disintegrate when the furnace is cooled down.
4. It must not crack when heated.

5. It must have sufficient mechanical strength to withstand the swash of the liquid masses in the furnace.

6. It must be fairly cheap.

To meet conditions 1 and 2 the stone must be rather pure, that is, free from silica and alumina, substances which act as acids to the bases of the stone, and by the formation of fusible compounds lessen its refractoriness.

To meet condition 3 a stone high in magnesia is necessary. Pure magnesite after calcination will only slake (or combine with water with the formation of a hydrate and consequent expansion and disintegration) with exceeding difficulty. Lime, on the other hand, slakes very rapidly, and hence gives a lining of poor durability. Calcined dolomite stands between lime and magnesite in this respect and, therefore, cost considered, makes the most satisfactory lining.

A stone suitable for lining basic open-hearth furnaces should fill the following specifications as to composition:

	Per cent.
Silica (SiO_2) under.....	1.00
Aluminum and Iron Oxides (Al_2O_3 , Fe_2O_3) under.....	1.50
Magnesium Carbonate (MgCO_3).....	35.00
Calcium Carbonate (CaCO_3).....	65.00

The more nearly the stone approaches magnesite (MgCO_3) the better. Dolomite and well-burned dolomitic limestone are more extensively used than magnesite because they are cheaper.

Analyses of limestones in actual use are as follows:

	Silica.	Iron and alumina.	Lime (CaO).	Magnesia (MgO).	Loss on ignition.
1. Dolomite	0.60	0.78	31.52	20.21	47.10
2. Same, Burnt....	1.00	1.80	64.48	32.16	0.56
3. Dolomite	1.11	1.35	30.67	20.45	....
4. Dolomite	0.72	0.99	31.15	20.36	....

Nos. 1 and 2 furnished by courtesy of Mr. G. F. Albrandt, Am. Rolling Mill Co.

Nos. 3 and 4 are limestones used by the Illinois Steel Co.

*Blast-Furnace Flux.**

A very large and important use of limestone is as flux in the iron-blast furnaces of the country. Approximately one-fourth of the total amount of stone quarried is used for this purpose, and according to the statistics of the U. S. Geological Survey 17,119,297 tons were thus consumed in 1907.

The value of a limestone as a blast-furnace flux is dependent on the following factors:

1. Physical condition, i. e., freedom from dust.
2. Purity, with respect to silica and alumina.
3. Purity, with respect to sulphur and phosphorus.
4. Proportions of lime and magnesia.

The factor of physical condition is of but minor importance, and in the vast majority of cases needs but slight consideration. It is only in the case of such materials as marl and travertine that dusting becomes serious, and with ordinary limestones the variations in amount of dust formed are inconsiderable and unimportant.

The chemical composition of limestone is, on the other hand, of the utmost importance, and in particular is this true † with respect to its content of silica and alumina. As the function of the limestone in the blast furnace is to furnish bases (lime and magnesia) to combine with and flux the acidic impurities in ore and coke, it is evident that its efficiency for this purpose will decrease very rapidly with increase in acidic impurities in the limestone itself.

This decrease in available bases may be readily calculated, provided we assume a definite ratio of bases to acids in the blast furnace slag. In practice this ratio is not definite but varies, not only with the kind of iron which is being made, but even from day to day in the same furnace. However, the amount of variation is not great, and if technical and com-

* The writers are indebted to John J. Porter, Associate Professor of Metallurgy at the University of Cincinnati, for the Analyses and Metallurgical formulas, employed in the use of limestone as a flux, etc., given in this report in the following discussion.

† Campbell, "The Manufacture and Properties of Iron and Steel," p. 190.

mercial, rather than scientific results are desired, are absolutely unimportant. By the inspection of a very large number of slag analyses, representing all sections of the country and all grades of iron, the ratio of 1:1, or lime plus magnesia divided by silica plus alumina equals 1, has been determined as a fair average value, and this value is used in the following calculations.

Let A be the per cent. of acids (Silica plus Alumina) in the stone. Then to flux these acids A per cent. of lime plus magnesia will be required, and $2A$ per cent. of slag will be formed. To convert lime into lime carbonate (CaO to CaCO_3) the factor is 1.785, while if the stone is pure dolomite containing 40 per cent. of MgCO_3 , the factor becomes 1.911. As most fluxing stone runs under 10 per cent. in MgCO_3 it will be better to take this conversion factor as 1.8. This gives the percentage of carbonates utilized in fluxing the impurities in the stone itself, as $1.8A$ per cent., wherefore the percentage of carbonates in the stone available for fluxing extraneous material is $100 - (A + 1.8A)$, or the "available carbonates" equal $100 - 2.8A$ per cent. This assumes that the limestone is composed entirely of CaCO_3 , MgCO_3 , SiO_2 , and Al_2O_3 , which, while not strictly true, is practically so, since all other constituents seldom total as high as 1 per cent.

Sulphur and phosphorus are usually present in limestone in minute amounts, but it is but seldom that their presence need cause concern.

Sulphur will certainly do no damage if not in excess of 0.5 per cent., and can probably be present in much larger amounts before its bad effects will become distinctly recognizable. It is very unusual to find over 0.1 per cent. in limestone.

Phosphorus is only important if the stone is to be used in the manufacture of bessemer iron. In this case it becomes highly important and should not exceed 0.01 per cent., preferably being even lower. In making other grades of iron, phosphorus in the stone would have to reach at least 0.1 per cent. in order to deserve consideration, whereas, as a matter of fact, it is exceedingly rare to find it even as high as 0.05 per cent.

The relative amount of lime and magnesia in the stone is also important, but in the present state of our knowledge it is next to impossible

to make any but the most general statements as to the proportions most to be desired.

The smaller atomic weight of magnesium (40 as compared with 56 for calcium) enables it to combine with a larger proportion of acids than calcium to form a slag of a given formula. For example, MgSiO_3 consists of 40 per cent. MgO and 60 per cent. SiO_2 ; while CaSiO_3 consists of 48.28 per cent. CaO and 51.72 per cent. SiO_2 . This is almost exactly offset by the smaller percentage of MgO in MgCO_3 , 47.62, as compared with 56 per cent. CaO in CaCO_3 . One pound of MgCO_3 will convert .2867 pounds of SiO_2 to MgSiO_3 , whereas 1 pound of CaCO_3 will convert .2896 pounds of SiO_2 to CaSiO_3 .

The specific heat of magnesia is considerably greater than that of lime (.224 as against .174). Hence the specific heat of magnesia slags is somewhat higher than in the case of lime slags, and slightly greater quantities of fuel are required to melt them.

Again, magnesia has less * affinity for sulphur than lime, the molecular heats of formation of magnesium sulphide and calcium sulphide being 79,400 and 94,300 calories, respectively. This means that a magnesia slag is less efficient in removing sulphur than a lime slag, and that, other things being equal, a more basic slag will be needed in the case of dolomite than if all limestone were used. It should, perhaps, be explained that the term "a more basic slag" is used in its strict chemical significance, and does not necessarily mean a higher percentage of magnesia. For example, suppose the normal slag to be CaSiO_3 , containing 48.28 per cent. of CaO , then the magnesia slag of corresponding basicity is MgSiO_3 , containing only 40 per cent. of MgO . As explained above, however, the amounts of the carbonates required to produce slags of equal basicity are the same in either case, and hence for the efficient removal of sulphur more magnesian stone will be required than in the case of purer limestone.

Practical experience in the use of dolomite containing 40 per cent. of MgCO_3 indicates that the fuel consumption is not invariably higher in spite of the unfavorable factors enumerated above. This is probably due

* Hofman, Iron and Steel.

to the fact that most magnesian slags are, when molten, more fluid than the corresponding lime slags. This, in many cases, results in better and more regular working of the furnace, thus indirectly accomplishing a counterbalancing saving in fuel.

It is quite evident from what has been said on this subject that our present knowledge of the quantitative effect of magnesia is very meager, and that it is impractical to consider it in any numerical comparison of the relative values of limestones.

The derivation of a rational formula or rule for the exact valuation of limestones used as furnace flux is of great practical importance, and will be attempted here. There are so many variable factors which in one way or another enter into such calculation that it is obviously impossible to take them all into account and obtain a scientifically exact formula of universal applicability. Fortunately, however, many of these factors vary but slightly from an average value, and moreover have but a slight quantitative effect upon the final results of our calculation. It is, therefore, entirely satisfactory from a practical standpoint to use these average values in deriving a formula which will be a suitable guide in estimating the value of stone.

As will have been gathered from the preceding discussion, it is necessary to base these calculations entirely on the silica and alumina contents of the stone. The effect of physical condition, magnesia, sulphur, and phosphorus are as a rule *nil*, and in the exceptional cases where they do effect the value the amount is incapable of being determined by any generally applicable rule.

The causes of the decrease in value of a limestone with the increase in per cent. of impurities may be summarized as follows:

1. Lower percentage of available bases.
2. Cost of coke to melt the extra slag formed.
3. Increase in manufacturing cost due to decreased output.

The first of these factors, the lower percentage of available bases, has already been discussed, and it was found that in any impure stone the available carbonates = $(100 - 2.8A)$ per cent., where A is the per cent. of silica plus alumina in the stone.

The weight of coke necessary to care for the slag formed from the impurities in the stone is evidently equal to the weight of slag formed times the weight of coke necessary to melt a unit of slag. As this weight of slag is 2*A* per cent. of the weight of stone used, the extra coke required per ton of stone is equal to 2*A*/100 times the weight of coke required per ton of slag.

This weight of coke per unit of slag may be calculated from several standpoints, as, for example, by the use of the principal of critical temperatures, from the heat-balance sheet of the blast furnace, and empirically from the results of practice. The calculations are very lengthy and involved, and the results depend upon the magnitude of many variable factors, such as the fusion point of the slag, the specific heat of the slag, the temperature of the blast, the per cent. of the carbon reaching the tuyeres, the per cent. of moisture in the blast, etc., etc. In order to get an answer it is necessary to give values to these factors, and this has been done, selecting average values applicable to Northern and Eastern practice. The resulting answer comes out .136 and .138 pounds of carbon per pound of slag by two theoretical methods, and .128 if worked out empirically from the results of practice. There is, therefore, assumed a carbon consumption of .13 pounds per pound of slag to be melted, or .1456 short tons of carbon per long ton of slag. The figures would be considerably greater for Alabama practice, but for Northern practice this value is believed to be safe and conservative.

If *C* stands for the extra coke, in short tons, required per long ton of stone; *P* be the price of this coke per short ton; *fc* be the per cent. of fixed carbon in the coke; and *A*, as before, the per cent. of acidic impurities in the stone, then $C = 2A \times .1456 / fc$. Adding 5 per cent. for breeze or waste coke, $C = 306A / fc$. While the cost of the coke to care for the impurities in one long ton of stone = $\frac{.306AP}{fc}$.

The manufacturing cost is also influenced by the impurity of the stone through the decreased output which is caused by impure stone, the output with any given ores and rate of driving being inversely proportional to the coke charged. That is, with a given volume of air blown

per unit time a given amount of coke will be burned per unit time, hence the larger the amount of ore accompanying this coke, or in other words the less the proportion of coke in the charge, the greater the output; or the output is inversely proportional to the coke consumption.

Let M = Manufacturing cost per ton of iron, pure stone basis.

C = Short tons of coke to care for impurities in one long ton of stone.

I = Increase in manufacturing cost per long ton of stone due to impurities.

S = Long tons of pure stone needed per ton of iron.

Ck = Short tons of coke used per ton of iron, pure stone basis.

A = Per cent. of silica plus alumina in stone.

P = Price of coke per short ton.

fc = Per cent. of fixed carbon in coke.

V = Value of pure stone.

V' = Value of impure stone.

Since the manufacturing costs per day are practically constant, the costs per ton of iron are equal to a constant divided by the output, or $M:1/\text{output}$.

But it has already been shown that the output is inversely proportional to the coke consumption, and, therefore, $M:Ck$, and also $M/S:Ck/S$.

In the case of the impure stone the manufacturing cost per ton of stone is $M/S+I$, and the coke used per ton of stone is $Ck/S+C$. Therefore,

$$\frac{M}{S}:\frac{M}{S}+I::\frac{Ck}{S}:\frac{Ck}{S}+C.$$

From this we get $I=MC/Ck$, or as C has already been found to equal $.306A/fc$, we have $I=.306MA/fc.Ck$.

By combining these expressions for each of the three factors affecting the value of any impure stone, an expression may be obtained for the value of the stone as follows:

$$V'=V(1-.028A)-\frac{.306AP}{fc}-\frac{.306MA}{fc.Ck},$$

or condensing

$$V'=V(1-.028A)-\frac{.306A}{fc}\left(P-\frac{M}{Ck}\right),$$

and from this expression, or from the constituent factors considered separately, it is easy to obtain absolute or relative values for any stone in any form desired.

Many furnace managers are losing money in buying stone, either by indifference and lack of knowledge as to the quality of the stone they are using, or through actually preferring a more impure stone at a few cents less cost per ton. Other more progressive managers realize fully the importance of the question, and insist on the highest obtainable quality of stone. The accompanying diagram (Fig. 16) shows graphically how serious is the effect of acidic impurities on the value of a fluxing stone, and will probably be a revelation to many persons.

Because of the fact that it is possible to use an impure stone, even up to 8 per cent. of silica plus alumina, and because commercial exigencies sometimes force the use of such stones, it is practically impossible to formulate a universally applicable specification for blast-furnace fluxing stone, although this may readily be done for any particular furnace or district. The following table gives analyses of fluxing stones actually in use at representative plants in various sections of the country, and will show far better than any specifications the range of composition permissible:

ANALYSES OF LIMESTONES USED FOR BLAST FURNACE FLUX.

District.	Silica (SiO_2).	Alumina (Al_2O_3).	Iron Oxide (Fe_2O_3).	Lime Carbonate (CaCO_3).	Magnesia Carbonate (MgCO_3).	Cost per ton, f.o.b. furnace.
Alabama	3.78	2.44	0.75	86.26	7.05	0.65
"	1.62	0.70	0.30	54.20	43.18	..
Canada	1.81	0.90	..	93.22	1.56	..
"	1.70	0.38	..	93.33	3.99	..
Illinois	1.93	1.29	1.10	94.20	1.10	..
"	1.01	0.99	0.40	54.88	42.76	..
Pennsylvania ..	6.50	2.05	0.45	88.00	3.00	0.70
" ..	3.90	1.88	0.52	92.20	1.50	0.80
" ..	0.90	0.48	0.20	97.26	1.05	..
Virginia	6.00	3.50	0.50	86.00	4.00	0.70
"	4.30	2.00	0.20	90.00	3.36	0.75
"	0.42	1.20	0.30	54.08	43.86	0.65

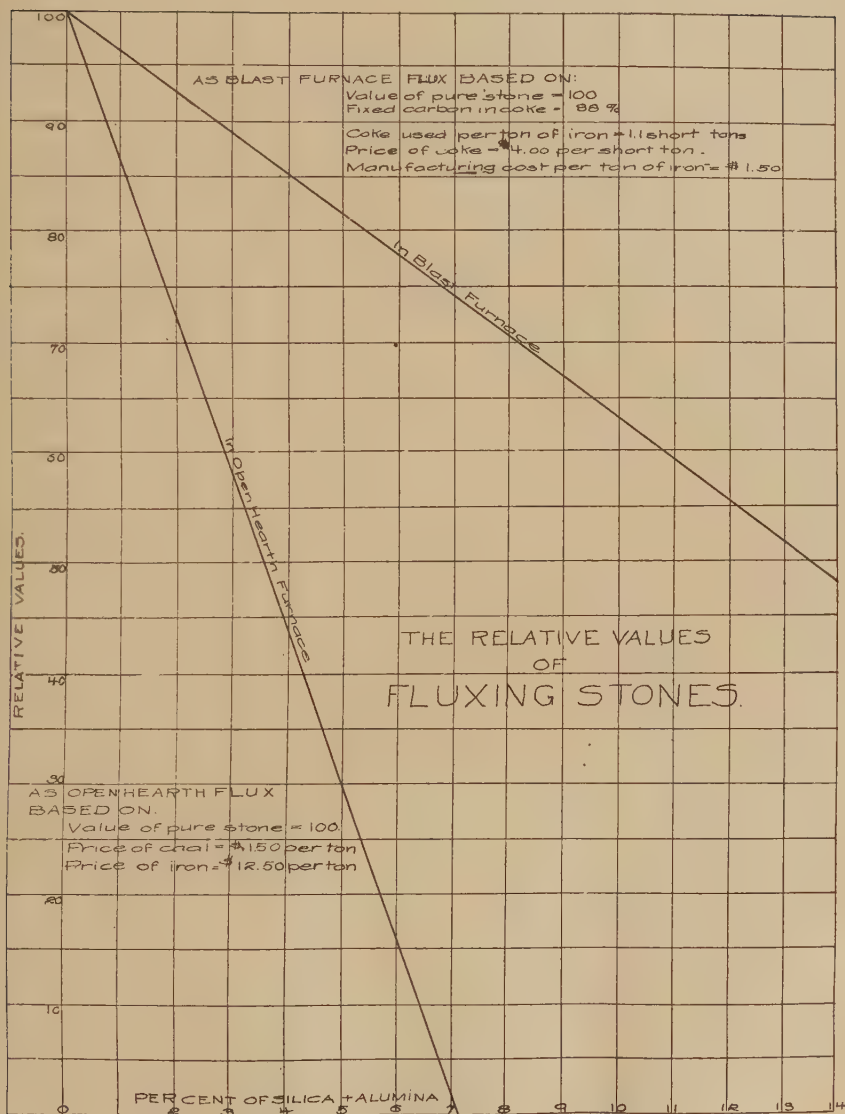


FIG. 16.—Diagram showing relative values of fluxing stones.

Basic Open-Hearth Furnace Flux.

The function of limestone in the basic open-hearth steel furnace is quite similar to its function in the blast furnace. That is, it is used to flux the silica and alumina present. The value, therefore, is dependent on the same factors as in the case of the blast furnace, but as the conditions are quantitatively different, so also the values of these factors are different.

As to physical condition, the freedom from dust is of rather more importance than in the case of the blast furnace, any dust being carried over into the checkers and causing these to deteriorate very rapidly. However, no great trouble is experienced with ordinary stones in this respect, and the factor is of very minor importance.

The purity, with respect to lime and magnesia, is, as before, the important point, but even more so now than in the case of the blast furnace. In the basic open-hearth furnace, because of the necessity of removing phosphorus and preventing the cutting out of the basic lining, it is necessary to carry an exceedingly basic slag, the usual limits and average composition of which are about as follows:

AVERAGE COMPOSITION OF BASIC OPEN-HEARTH FLUX.

	Maximum.	Minimum.	Average.
Silica (SiO_2)	25.00	10.00	17.00
Alumina (Al_2O_3)	6.00	1.00	3.00
Iron Oxide (Fe_2O_3)	25.00	10.00	19.00
Manganese Oxide (MnO)...	15.00	3.00	6.00
Lime (CaO)	50.00	35.00	44.00
Magnesia (MgO)	10.00	4.00	6.00
Phosphoric Acid (P_2O_5)....	15.00	2.00	5.00

In this case it is seen that the average ratio of lime plus magnesia to silica plus alumina is 50/20 or 2.5, so that we have: Bases necessary to flux the acids in the stone equals $2.5A$, or carbonates equals 1.8 by $2.5A$, and the percentage of available carbonates in the stone $=100 - 1.8 \times 2.5A$, or $=100 - 4.5A$.

Sulphur and phosphorus are here again of but minor importance. Sulphur should not exceed 0.5 per cent., and phosphorus 0.1 per cent.,

but as these impurities seldom reach these limits in commercial stones it is rarely necessary to consider them.

The relative proportions of lime and magnesia need some consideration. A high percentage of magnesia is not desired in the slag, as it has a poorer affinity for sulphur and phosphorus than the lime which it replaces. However, magnesia in the form of dolomite is desired for patching bottoms, as described under the head of furnace linings, and used in this way portions of it dissolve in the slag, so that it becomes a flux as well as a lining. We may, therefore, value the stone used for lining as though it were a flux, counting magnesia as equivalent to lime, but in the flux proper it is desirable to hold the magnesia as low as possible.

The derivation of a rational formula for the valuation of limestones used in basic open-hearth practice is subject to the same difficulties as in the case of the blast furnace, and is gone about in the same way. The causes of the decrease in value with increasing impurities are practically the same, as follows:

1. Lower percentage of available bases.
2. Cost of fuel to care for extra slag formed.
3. Increase in manufacturing cost due to decreased output.
4. Value of iron lost in slag.

The lower percentage of available bases has already been considered and the percentage of available carbonates was found to be 100—4.54.

The cost of fuel to melt the extra slag formed is, of course, equal to the weight of slag times the weight of fuel to melt a unit of slag times the cost of fuel. The weight of slag is equal to .054 (see average analyses above). The fuel to melt the slag is more difficult to calculate. There is but little published data on the subject on which to base calculations, and, as in the case of the blast furnace, the exact calculation involves innumerable variables. However, based on average practice we may assume the following conditions:

Coal used contains 8000 pound calories per pound.

Fifty per cent. of the heat generated by the coal is absorbed in one way or another in the furnace proper.

Total heat in 1 pound of molten slag equals 500 pound calories.

We have, now, pounds of coal used per pound of slag formed equals: Heat in 1 pound of slag, plus Heat to decompose carbonates represented by 1 pound of slag, divided by Calorific value of coal, times .50, or =

$$\frac{500 + .44 \times 451 + .06 \times 350}{8000 \times .5} = .18 \text{ pounds.}$$

And, Cost of coal to care for extra slag formed = $.18 \times .05A \times \text{Price coal per ton} = .009AP$.

The increase in manufacturing cost due to impurities is caused in two ways.

Referring to the table of slag analyses it will be seen that each pound of slag retains on the average .19 pounds of iron oxide, equal to $.19 \times 56/72$, or .14 pounds of iron, and the output may be regarded as being decreased by this much for every pound of slag present. This decrease in output is then one source of the increase in manufacturing cost.

Again, a given amount of heat supplied to the furnace may be regarded as producing a certain weight of steel under any given set of conditions. If now one of these conditions is altered, i. e., the amount of slag present is increased, some of the heat will be required to care for this slag, less will be available for the production of steel, and if the heat supplied per unit time be constant, the output per unit time will be decreased. This is the second source of increase in manufacturing cost.

Both of these items come out practically *nil* under all ordinary conditions of practice, but the expressions are given here, chiefly as a matter of interest. They are readily derived in a manner similar to that used in the case of the blast-furnace calculations, only assuming that 600 pounds of coal are used per ton of steel produced.

Increase in manufacturing cost from decreased output due to loss of iron in extra slag = $M \left(\frac{.007SA}{1 - .007SA} \right)$.

Increase in manufacturing cost due to heat consumption of extra slag

$$= M \left(\frac{36.A}{2,400,000 - 36.AS} \right).$$

Where M is Manufacturing cost per ton of steel, pure stone basis.

S is Tons of stone used per ton of steel.

A is Percentage of silica plus alumina in stone.

Coming now to the last item, value of iron lost in extra slag formed, this is equal to: Weight of slag per ton of stone, times the per cent. of iron in slag, times cost of iron; and this expression reduces to $.007AP'$, where P' is the price of iron (pig iron or scrap) used, per ton.

Finally, the expression for the value of any impure stone, neglecting increase in manufacturing cost as unimportant, becomes $V' = V(1.00 - .045A) - .009AP - .007AP'$. The symbols used having the same meaning as before.

On the diagram (Fig. 16) the lower line shows how rapidly the value falls off as the impurities increase. This rapid decrease in value is well recognized by practical steel men, who, therefore, insist on the very highest grade of stone for this purpose. Specifications usually run about this way:

	Per cent.
Silica, under	1.00
Alumina, under	1.50
Magnesia, under	5.00

while analyses of stones actually in use are as follows:

	Ohio.	Illinois.	Pennsylvania.
SiO ₂	0.68	1.15	.94
Al ₂ O ₃	1.53	.81	.82
Fe ₂ O ₃	0.47	.40	.64
CaCO ₃	93.86	97.07	94.73
MgCO ₃	4.22	.50	2.97
	100.76	99.93	100.10

LIMES AND CEMENTS.

When natural limestones are "burned," i. e., heated to a temperature of 925° C., the chemical union of the constituents is broken down and the gaseous CO₂ is driven off. The remaining substance, CaO, possesses properties quite different from the original stone which makes the mass available for many purposes. These properties depend upon the methods of treatment employed and the character and amounts of the impurities contained in the original rock. The products likewise differ. By suitable processes the limestone by itself may be changed to caustic, hydrated,

or hydraulic limes or to natural cements. By the addition to the limestone, before burning, of certain necessary materials in proper proportions the product may be Portland cement. The following pages will include a full discussion of the methods of burning and the resulting products, including limes, natural, and Portland cements.

BURNING OF THE LIMESTONE.

The fact that limestones when burned lose part of their constituents and acquire new and valuable properties was known by the ancients, and from their day to the present limestones have been burned in various ways from the crude heaps of wood and stone of the pioneers to the more complicated and permanent continuous kilns of the cement manufacturers.

The kilns in which the limestone, shell, or marl is burned differ widely. The crudest method of burning consists in arranging a pile of logs and limestone so as to admit air freely to facilitate the burning of the fuel with the limestone, or whatever raw material may be used.

The types of kilns employed in lime-burning vary both in form and construction all the way from the crude type just mentioned to kilns built of solid masonry or constructed of boiler plate and lined on the inside with fire-brick. The different types that are in use may be grouped under two main classes:

Intermittent kilns.

Continuous kilns.

Intermittent Kilns.

This type of kiln is one of the more primitive employed, and since each burning of a charge constitutes a separate operation it is equally as un-economical as it is primitive. There is a great waste of heat. After the kiln is charged and burned the operator must wait for it to cool. When it has cooled and the charge is drawn then the kiln may be recharged. Each time the kiln must again be reheated—a process involving both loss of time and a waste of fuel.

The intermittent kiln is usually located on the side of a hill, and is crudely constructed of stone and so situated that the top is accessible for charging the kiln and the bottom for drawing lime and supplying fuel. It has obvious disadvantages; yet in rural districts far from the railroad and with abundant and cheap fuel, this antiquated type of kiln suffices for the purpose for which it is constructed, namely, that of supplying a small and irregular demand. Old kilns of this sort can still be seen in farming regions in Maryland, in certain sections of the Piedmont, and are employed in burning such lime as the neighborhood demand requires.

Continuous Kilns.

There are three different types of continuous kilns in general use. These are (1) the vertical kiln with mixed feed, where the limestone and fuel are fed in alternate layers, and (2) the vertical kiln with separate feed, where the limestone and fuel are not brought into contact, and lastly (3), the chamber or ring kiln.

The vertical kiln built of stone with mixed feed is the type of kiln most widely used in Maryland. First a layer of coal and then a layer of limestone is fed in at the top, the fire is started at the bottom and works its way up. The process of charging is constantly kept going, the kiln being charged with fuel and limestone at regular intervals, and the calcined product drawn out below.

The construction of these mixed-feed kilns is cheaper than that of either the separate-feed or the chamber or ring-kiln, and in this respect has the advantage over both. Moreover, they are more economical of fuel, and, for the same size of kiln, they yield also a larger product, but the quality of the lime is on the whole of a lower grade than that manufactured in either one of the other types just mentioned.

In the mixed-feed kiln the commingling of the fuel and stone results in the ash of the fuel being more or less mixed with the lime. Also a part of the lime and ash in the superheated portions of the kiln often fuse and form a clinker on the outside of the burned lumps. These have to be discarded as well as a portion of the product which is dis-

colored by contact with the fuel. By the use of kilns where the fuel is not in contact with the stone the formation of a clinker is avoided and a better product for building is obtained. The clinker that is formed when the limestone and fuel are in contact might be used and sold, after grinding it to a powder, as hydraulic material. Usually though, the amount is relatively small and it is, therefore, considered better to discard it, casting it aside as a more or less unavoidable waste product: unavoidable, that is, when the continuous-mixed feed kiln is used, though the quantity of clinker may be reduced to a minimum by careful burning. Not infrequently the clinker lumps and under-burned stone are not separated from the product of the kiln and all are put through the pulverizer together, and so the clinker and under-burned stone thus become part of the finished product with which it is so intimately mixed and forms so small a proportion of the whole that it is extremely difficult, except by chemical means, to detect its presence. This under-burned and ground limestone that forms the core of the under-burned lime lumps when ground to a powder for agricultural use, when the lime is made from a very pure limestone, is about half as effective, weight for weight, as the caustic lime. It reacts more slowly, and so its beneficial results are not seen so soon.

Fuel in Burning Lime.

Theoretically, 112 pounds of coal will burn a ton of limestone, or, in other words, it requires 11 pounds of coal to calcine 200 pounds of lime. As a matter of fact, in actual practice, it requires 187 to 375 pounds of coal to burn 1 ton of limestone, even using the most modern kilns. The upper limit is even then generally exceeded, being about 475 pounds instead of 375 pounds. One of the greatest economies that can be effected in the manufacture of lime is, obviously, in the prevention of a wasteful use of fuel.

The range of cost to manufacture a ton of lime, which usually contain about 25 bushels, each bushel weighing about 80 pounds, is in Maryland from 6 to 9 cents per bushel, and the selling price varies from 8 to 17 cents, depending on the grade of lime and the market. Ten to 20 cents

per bushel, rarely less, is the usual price paid by farmers in Maryland who buy lime for use for agricultural purposes.

LIMES.

The limes produced by the calcination of limestone vary according to the composition of the original stone and the manipulation during or subsequent to its burning. Limestones of a fair degree of purity when burned yield caustic lime (CaO) which has the property, when mixed with water, of combining with carbon dioxide of the atmosphere to form calcium carbonate, thus returning to its original composition. Substances which harden through the process of returning to the chemical composition possessed prior to their burning or calcination are classed as simple cements. In this group are included caustic, magnesian, and hydrated limes.

Limestones carrying appreciable amounts of argillaceous impurities, namely, silica, alumina, and iron, when burned, undergo chemical changes by which the impurities unite with the lime to form new complex compounds. The products resulting from the formation of new compounds are classed as complex cements. In this group are included natural and Portland cements. In classification hydraulic limes, which are made from limestone containing more lime than necessary to combine with the contained impurities, may be grouped between the simple and complex cements.

The discussion of the following pages naturally divides itself into descriptions of caustic, magnesian, and hydrated limes; hydraulic limes and natural cement. The discussion of Portland cement, which involves the addition of other raw materials to the limestone before burning, is reserved for subsequent treatment.

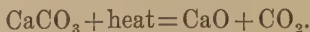
According to the character and quantity of impurities in the burnt product, limes are classified as

1. Caustic limes.
2. Magnesian limes.
3. Hydrated limes.

Caustic Lime.

When a lime contains from 5 to 10 per cent. of impurities it is known and marketed as caustic or high calcium lime.

The reaction that takes place as the result of raising the temperature of limestone to the point of decarbonation may be expressed by the following formula in which the carbon dioxide (CO_2) of the second part of the equation passes off into the air, leaving calcium oxide or "quick lime" in the kiln.



A considerable amount of this heat is released when water is added to caustic lime and it goes through the process of "slaking." The water combines with the lime to form hydrated calcium oxide or slaked lime, which has the formula $\text{Ca}(\text{OH})_2$. Exposed to the atmosphere the hydrated lime gradually takes up carbon dioxide forming according to the equation $\text{Ca}(\text{OH})_2 + \text{CO}_2 = \text{CaCO}_3 + \text{H}_2\text{O}$ calcium carbonate and water. The water evaporates while the calcium carbonate remains, cementing the surface of the now hydrated lime, and thus retards the recarbonation of the whole.

In preparing mortars a certain amount of sand, etc., is added to lower the cost and increase the volume and prevent shrinking as it dries. It has been suggested that a small portion of the sand combines with lime and forms silicates, but it is very doubtful whether this is the case. Examinations of old mortars have shown that their extra hardness is probably due almost entirely to more complete recarbonation, and only in a subsidiary way to the formation of silicates.*

If calcium silicate is formed from the combination of lime and the silica added as sand, it takes place very slowly, the per cent. of calcium silicate formed increasing with the age of the mortar, as was shown by the analyses which were made by Petzhold on mortars 100 to 300 years in age. Lime-cement mortars are being used largely at present, and by many architects and builders are preferred to any other sort, because their hardening, is not surficial, like the lime-sand mortars, but uniform

* Buchler, H. A. Lime and Cement, Mo. Geol. Survey, Vol. VI, p. 35.

throughout the mass. The lime-cement mortars are also stronger, more durable, and less likely to crack. The lime-cement mortar is obtained from mixing equal parts of cement and hydrated lime.* Lime-cement mortars are also water-proof, and hence hydrated lime is often used in cement mortars to make them water-proof. Lime-cement mortars trowel more smoothly than do cement mortars alone.

Magnesian Lime.

Limes containing more than 5 to 10 per cent. of MgO are classified as magnesian limes. The per cent. of magnesia, however, in a large proportion of the commercial magnesian limes is generally much higher than 10 per cent., ranging from 10 per cent. upwards to 41.65 per cent., the higher limit being the per cent. of magnesia present in a lime made from burning a pure dolomite. When the lime contains from 10 to 20 per cent. MgO the term dolomitic lime is more suitable and more commonly applied than the term magnesian lime.

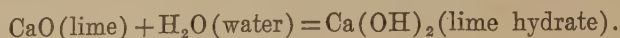
The content of magnesium oxide in magnesian limes produces several noticeable effects which may be briefly stated. When water is poured on magnesian limes they not only slake more slowly but also give off less heat than the caustic, fat, or high-calcium limes. The magnesian limes are made in the same way as caustic limes, except that less heat is required for calcination. Also they expand less and set more rapidly than the high-calcium limes, and under certain conditions of burning have hydraulic properties. This, however, appears to be due, as in the case of the burned products derived from magnesites, to the formation of hydroxides in the place of carbonates. They also have hydraulic properties, but due to another cause when they contain sufficient impurities in the form of silica, iron, and alumina, and in this latter case the burned product is discussed and classified with the complex cements, which are considered later.

Hydrated Lime.

Hydrated lime is obtained by treating caustic lime with water which combines with the lime to form $\text{Ca}(\text{OH})_2$. The following chemical

* Buehler, H. A. Lime and Cement, Mo. Geol. Survey, Vol. VI, p. 24.

equation expresses the reaction that takes place between caustic lime and water and shows how this new compound, hydrated lime, is formed:



If the lime is free from impurities the amount of water necessary to effect complete hydration in 32.1 per cent. of the weight of the lime. A less amount of water than the theoretical quantity, however, is required to thoroughly hydrate caustic limes because of the impurities that are always found in greater or less quantity in all commercial limes.

A very small portion of the lime manufactured in Maryland is hydrated, though there exists a very active demand for lime of this sort. The M. J. Grove Lime Company, of Frederick, and the Le Gore Lime Company, of Le Gore, also in Frederick County, the latter located on the Northern Central Railroad, and the former on the Baltimore and Ohio Railroad, are the only two operators in Maryland that systematically hydrate a portion of their product to meet this present and growing demand. Beginning April 1, 1910, hydrated lime will be placed on the market by the recently constructed plant of the Tidewater Portland Cement Company, at Union Bridge. To meet the constant inquiries made with reference to hydrated lime, its manufacture, chemical composition, physical appearance, general properties, and uses it has seemed advisable to state the following facts:

MANUFACTURE OF HYDRATED LIME.—In preparing hydrated lime on a commercial scale three stages of manufacture are necessary. These are:

(1) The lump quicklime must be ground to a fairly uniform small size.

(2) The powder or grains resulting must be thoroughly mixed with sufficient water, when the grains become a fine powder.

(3) The slaked lime must finally be sieved to separate out unhydrated lumps and cores from the fine powder.

Numberless patents have been issued to cover one or more of the points above named, but the general stages are the same in all. These will now be taken up separately and briefly discussed.

Grinding of Quicklime.—Although grinding is practiced at most hy-

drated lime plants, great variations exist in the extent to which it is carried. In a few plants the quicklime is simply crushed to about 1-inch sizes, while at others the quicklime is first crushed and then reduced to a powder, the greater portion of which will pass a 50-mesh sieve. The plan adopted in the most successful hydrating plants consists in crushing the lime by means of a pot crusher or Sturtevant Open-Door Crusher. This reduces it to pieces about $\frac{1}{2}$ inch and under. It is well to note here that in burning lime which is to be hydrated, it is not necessary to employ such a high temperature as is ordinarily used. Where lime is transported in lumps, it is found necessary to partially vitrify the outside of these in order to prevent their falling to pieces in the cars. Where the lime is to be hydrated, however, this is unnecessary, and all that is required is to have all of the carbon dioxide driven off, which may be effected at a temperature of less than 1000° C.

Mixing with Water.—There are quite a number of processes and machines for hydrating lime. The only two, however, which are used to any very great extent are the Kritzer and the Clyde. The latter of these two machines has given entire satisfaction when used for hydrating magnesian limes. With high calcium limes, however, the slacking takes place very quickly, and for these the Kritzer process is now being more extensively employed.

The Clyde process hydrator is a batch machine in which a given quantity of lime, usually 1 ton, is placed, and to this is added the proper quantity of water by means of a spray. The machine itself consists of a revolving pan provided with plows, which stir up and mix the water and the lime. The water is weighed and added in a predetermined amount. When the operator judges the process to be completed, the lime is scraped from the pan through an opening in the center of the pan into a hopper below the hydrator, when it is ready for sieving.

The Kritzer process is a continuous one. The hydrator consists of a number of cylinders, one over the other, which are provided with paddles revolving around a central shaft. The lime is fed into the upper cylinder in a continuous stream and here water is sprayed upon it, the amount being regulated by valves. The moist lime is worked by the paddles and

passes from the upper cylinder to the lower ones. When it finally works its way out of the bottom cylinder, it is entirely hydrated and dry. The steam from the lower cylinders passes up through the upper ones and helps to hydrate the lime.

The amount of water to be added in each case is determined by experience. The more calcium oxide the lime contains, the more water must be added.

Sieving the Product.—After slaking, the lime is in the form of a very fine, light, fluffy powder, all of which will pass through a very fine sieve. It, usually, contains, however, cores of unslacked lime. These latter constitute the siliceous portions of the limestone, which have been partly vitrified. They are separated from the hydrate by sieving. This is usually done by means of an inclined screen, several forms of which are upon the market. In one type the sieve oscillates, in another the wire cloth is covered by small metal bands, upon which hammers fall and bounce the material through. The cores are often ground finely in a Fuller-Lehigh mill and sold for agricultural lime.

Packing the Product.—Hydrated lime is now very conveniently packed in paper bags, and automatic sacking machines have been devised which allow it to be packed very rapidly in bags which are pasted shut before the lime is placed in them, this latter being done by means of a valve in the bag. These bags present a square appearance, and not the ragged end of a hand-tied bag.

Cost of Equipment.—A plant for the hydration of magnesian limes, having a capacity of 3 tons per hour, can be equipped for about \$5000. This does not include buildings, which would probably add \$2000 to this. A plant of double this capacity could be built for about \$7000, exclusive of buildings. The first plant would require about 30 H. P. and from four to five men, while the second plant would employ from six to eight men and require from 40 to 50 H. P.

The equipment of a plant for the hydration of high-calcium lime by the Kritzer process, having a capacity of from 4 to 5 tons per hour, would cost \$12,000, to which must be added the cost of the building. From

four to five men would be required for the operation of the plant, and about 50 H. P. would be needed.

Cost of Hydration.—Manufacturers very often calculate that the cost of hydrating lime is borne by the increase in product, for instance, in hydrating a ton of lime (2000 pounds) there will be obtained from 2400 to 2600 pounds of hydrated lime.

PROPERTIES OF HYDRATED LIME.—Hydrated lime has certain properties that give it a great advantage as a marketable product over the unhydrated or caustic lime. For example:

1. It will keep indefinitely when packed in barrels or sacks or even paper bags.
2. It can be shipped by water and can be stored without danger of causing fire.
3. It does not expand when water is added and consequently can be packed and shipped in sacks.
4. Its mortar shows less danger of "popping" in the wall as sometimes occurs when incompletely hydrated caustic lime is used.
5. It may be added to cement either for the purpose of water-proofing the latter or to make a more easily troweled mortar.

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Uses of Lime.

The foregoing discussion of the limes has been classified according to their composition and method of manufacture. In the following pages

they are considered according to their uses. Broadly speaking the uses of lime may be classified into four groups:

1. Building material, as mortars or building limes.
2. Soil amendent or fertilizer or agricultural lime.
3. Chemical uses.
4. Metallurgical uses (see pp. 234-249).

BUILDING LIMES.—Both the caustic and magnesian, or dolomitic, limes are used for building purposes. The caustic limes are generally preferred because of their quicker setting properties, but locally this is not the case. The magnesian limes are sometimes preferred by reason of the fact that they possess the property of setting more slowly than the caustic limes and are “cooler working,” since when water is added they slake more slowly and hence release less heat. The fact that the magnesian limes are “cooler working” sometimes results in their being used without being completely slaked, their “cooler working” suggesting to the laborer accustomed to work with caustic limes a state of complete hydration before the hydrating process or slaking is completely finished. Limes that contain considerable quantities of silica, alumina, and iron—the argillaceous limes—are, however, not viewed with favor because of their hydraulic properties, and because of their iron content which gives the lime a dark color. There is no reason though why they could not under certain circumstances be used to advantage.

AGRICULTURAL LIMES.—The term “agricultural lime” has come into use as a trade name, but lime used for agricultural and lime used for building purposes differ in no way whatever that can be distinguished chemically. The lime that is sold to the farmer and the lime that the manufacturer ships to the builder may be used indiscriminately for either purpose. The term “agricultural lime,” however, is sometimes applied to building lime that has been either air or water slaked. The same term is used also in reference to the quality of the stone from which the lime is derived, and further in reference to the inferior quality of the product. Thus a lime which would not be acceptable to the builder might nevertheless be profitably employed for agricultural purposes by the farmer. But the farmer is almost as particular about the grade or quality of the lime

he uses as the builder is, and insists on a high-calcium lime and demands the same product from the kiln that the builder buys.

Lime has been used more or less extensively for agricultural purposes for a very long time. It is known to have been used on land to some extent before the beginning of the Christian era. However, its more extensive use in America dates from the first of the nineteenth century. Since then the practice of applying lime to soil has become very common and its value in improving the productiveness of the soil is well recognized. It has been shown not only to add to its productivity, but also when used in connection with other fertilizers to actually lessen the total cost of fertilization.*

At present a very large proportion of the lime manufactured is used by those engaged in agricultural pursuits. Especially is this true as to a great and increasing number of the farmers of Maryland, among the more educated and intelligent of whom liming the land is rightfully regarded as an absolute necessity.

Until within a comparatively recent period the chemical and physical effects on the soil resulting from applications of lime have been but slightly studied and very little understood. Investigations that have been carried on have shown that lime in itself is of little value except as an indirect fertilizer.

When a soil is treated with lime the latter unites with other substances in the soil and compounds are formed which have an important influence on the fertility of the land. Alumina and silica are the two principal clay substances, and lime unites with these to form double silicates. The double silicates, in which lime replaces part of the alumina, have also an affinity for and combine with ammonia, potash, and soda. The soda replaces the lime, which in turn may be replaced by potash or ammonia.

Lime also reacts with the potash feldspar fragments that may occur in the soil, releasing the potash which then combines with the double silicates of alumina, thereby becoming available as a plant food. Lime

* Md. Agric. Exp. Station, Bull. 110.

reacts with manures and organic compounds, and promotes the formation of ammonia and double silicates. If the manure is applied too abundantly a great part of the ammonia is driven off and lost, and much of the organic matter is destroyed.

Phosphoric acid, combined with iron and alumina, is potential as a plant food, but in this form is inert. When, however, these phosphates of iron and alumina come in contact with lime reactions result which make the contained phosphorus immediately available for plant consumption. Lime is further of value in neutralizing the organic acids. These acids result from the decomposition of plants of all sorts. They occur on both wet and dry soils, but are developed chiefly on the former. The presence in the soil of a large amount of these "humic" or organic acids is especially favorable for the growth of many coarse and undesirable plants. On the other hand, they seriously interfere with the growth of nitrifying ferments and hinder also the development of leguminous and a great number of other useful plants. A slight amount of acidity of the soil, however, is considered not undesirable, but to correct any excess of it lime is probably the best and most economical substance that could be used.

The chemical reactions that take place between lime and the constituents of the soil result in some very important physical changes. This is particularly noticeable in soils which are either very clayey or very sandy. The clayey soils generally show a marked tendency to remain cold and moist, to compact and to harden. The sandy soils, however, are more porous, absorbing water with a much greater avidity than clayey soils, but retaining it in the form of moisture for a much shorter period.

Lime when applied to clayey soils groups the fine particles together. The reaction that results in this condition is known as "flacculation." The soil becomes more porous and friable. Openings occur which not only permit the freer descent and absorption of water by the soil, but also augment the passage of moisture upward by capillarity. Besides this these new and enlarged openings allow an increased passage through

the soil of both heat and air, thus promoting nitrification and bringing about a more comfortable environment for the growing plants.

When lime is added to sandy soils the object is not to create better conditions for nitrification but to bring about reactions between the lime and the constituents of the soil whereby new and better physical conditions for plant life are brought about. A short distance below the surface a more or less impervious layer forms what is known as a "hard-pan." This arrests the too free passage of water downward. Lime on sandy soils has, therefore, a cementing action. The silicates that are formed hold the soil together, and consequently the porosity of the soil is diminished. Hence the soil will then absorb somewhat less water, but what it does absorb it will retain in the form of moisture for a much longer period than in the more porous state that existed before the application of lime.

The physical changes resulting from the chemical reactions between lime and the constituents of dominantly sandy soils is thus seen to be quite the reverse from that taking place between lime and the constituents of clayey soils. In sandy soils the ratio of iron and alumina to silica is very different from this same ratio in clayey soils, and hence compounds are formed in the one case that are physically very different from those of the other.

The condition of the crops more than anything else determine whether the land needs an application of lime, and numerous easy methods have been proposed for determining its necessity, but none of them are very reliable. A simple test that is probably as good as any is to wet a sample of the soil and bring in contact with a piece of blue litmus paper. If this turns red very rapidly it is an indication that the soil contains a considerable amount of acid and would be benefited by an application of lime.

The residual soils of limestone regions are often as much in need of applications of lime as the soils derived from other and more acid rocks, such as sandstones or shales. This is because in time the original lime in the soil is dissolved and leached out by descending carbonate waters,

leaving the soil cherty, siliceous, and ferruginous, and greatly diminished in productivity.

There is no little difference of opinion among farmers on the question of liming land. The great majority of them, however, have been convinced of its beneficial effects by resulting increased yields in their crops. Some of them think that the lime should be applied in large quantities and at intervals of several years, and others are of the opinion that better results are obtained by using smaller amounts and making more frequent applications. The amount used per acre, either in the case of small and frequent applications, or where the farmer applies large amounts at intervals of a period of years, vary in different sections. This is due to a small extent to the custom of the neighborhood, but more especially and frequently it is because of the differences existing between the soils of the separate sections.

Investigations that have been carried on and are still in progress at agricultural experiment stations in different parts of the United States to determine the amount of lime that should be applied per acre and the intervals at which the land should be limed, point to the fact that the best results are obtained by the application of small amounts at frequent intervals. The old idea that an acre should be treated with 100 bushels of lime at long, instead of with smaller amounts at frequent, intervals has been shown to be a mistaken one. It has been demonstrated that the crops are more benefited by applications of small amounts made annually than by large amounts applied every three or four years. Also, it is now generally recognized that a single application to poor and sandy soils should be small, and that the applications should be made annually.

As to the number of bushels of lime and frequency of application some very interesting and instructive results are presented in the Maryland Agricultural Experiment Station Bulletin No. 110 (p. 9). These results are tabulated in the table which is quoted below. It is very clearly brought out that 20 bushels of lime to the acre, applied annually, is proportionately more effective when the cost of the lime and results are considered than applications of 50 to 60 bushels.

VALUE OF GRAINS PRODUCED PER ACRE WITH DIFFERENT QUANTITIES OF LIME.
(IN DOLLARS AND CENTS.)

	Quantity of lime, bu.	Value of lime, dollars.	Value of gain of corn at 80c. bu., 1896.	Value of gain of wheat at 90c. bu., 1897.	Value of gain of hay at 50c. cwt., 1898.	Value of gain of corn, 1899.		Total value of grains.	Relative profits from grains.
						Gain at 40c. bu.	Fodder at 20c. cwt.		
1	10	1.80	2.88	3.06	7.45	3.28	0.09	16.16	14.36
2	20	3.60	2.79	4.59	6.78	4.60	0.54	19.30	15.70
3	none	..	..	..	..	..	..	....	....
4	30	5.40	2.85	5.49	5.97	3.12	0.72	17.97	12.57
5	40	7.20	3.24	8.37	6.55	3.80	0.45	22.41	15.21
6	none	..	..	..	..	..	..	....	....
7	50	0.00	3.75	7.56	5.60	5.12	0.63	22.66	13.66
8	60	10.80	4.05	8.91	6.37	6.16	0.99	26.48	15.68

A number of different kinds of lime are used for agricultural purposes. These are (1) high-calcium limes, (2) magnesian limes, (3) oyster-shell lime, and (4) slaked or hydrated lime.

A high-calcium lime is made from burning a limestone analyzing from 50 to 55 per cent. calcium oxide and 40 to 55 per cent. carbonic acid, and containing small percentages of magnesia, silica, iron, and alumina. A lime derived from a stone of this character would yield 90 to 98 per cent. of calcium oxide, and would weigh directly after withdrawal from the kiln 90 to 95 pounds to the bushel, and will slake about 3 bushels for 1 in volume.

Magnesian limes used in agriculture run from 5 to 20 per cent. in magnesia and 70 to 85 per cent. in calcium oxide. They weigh less than the high-calcium lime. A bushel of magnesian lime weighs about 70 pounds, and slakes about 2 bushels for 1 in volume. Oyster-shell lime weighs about 60 pounds to the bushel and contains from 85 to 95 per cent. of CaO.

CHEMICAL USES OF LIME.—Lime is used in chemical processes either unslaked as it comes from the kilns, or slaked to the hydrated form when it is used either dry or mechanically suspended in water as "milk of lime." It is also used in solution as lime water to a small extent. In all cases, except the manufacture of caustic alkalies, a magnesium-pure calcium-rich lime is preferred.

Unslaked Lime.—Unslaked lime is used for the manufacture of calcium carbide and cyan amide and as a cleansing or refining agent in the manufacture of glue and sugar, in the tanning of hides, and in the dyeing of textile fabrics. *Calcium carbide* is obtained by fusing a mixture of unslaked lime and carbon, in the form of coke or charcoal, in an electric furnace. The process demands considerable electrical current compared with the value of the product, and is usually limited to localities where abundant waterpower warrants the erection of large hydro-electrical plants. Calcium carbide is used in the making of acetylene gas and in the preparation of cyan amide. *Cyan amide* or “lime nitrogen” is manufactured by the use of either calcium carbide or, what in the end amounts to the same thing, a heated mixture of lime and coke, over which is passed nitrogen gas obtained from liquid air. All the steps in the process by which this substance is made have been patented since cyan amide bids fair to become one of the most important fertilizers in the market. It can also be used in the manufacture of ammonia.

Lime unslaked, or hydrated in the form of “milk of lime,” has the power of dissolving certain organic tissues, thereby disintegrating particles of flesh, and of absorbing fatty substances and oils with saponification. This renders the material valuable in the preparation of glue and the tanning of hides. *Glue* is manufactured from raw materials, chiefly slaughter-house and fishery refuse, which has been treated with lime for a period of six weeks to several months to remove the oils, flesh and blood, and to soften the more resistant tissues and marrow. Lime is also used in the early stages of the *tanning* processes where the hides are “limed” to saponify the fats and break down the particles of flesh adhering to the skin. The lime also attacks the epidermis of the hides and is very serviceable in loosening the hair and softening or “plumping” the leather. Lime is also used in the manufacture of *sugar* when the so-called second molasses, containing about 40 per cent. sugar, is treated with quick-lime to produce an insoluble tricalcium sucate which may be filtered off and subsequently decomposed with carbon dioxide yielding calcium carbonate and a solution of sugar. This process is particularly used in beet-sugar refining.

Slaked Lime.—Slaked lime is used dry in the preparation of bleaching powder, or chloride of lime, which is largely demanded in the industries or as a disinfectant. The slaked lime is placed in leaden vats and treated with chlorine gas. The use of slaked lime suspended in water in the form of minute particles—milk of lime—is perhaps the most commonly employed form in chemical industries. In this form it is used in the manufacture of ammonia, caustic soda and potash, the purification of water, the refinement of sugar, and also in tanning and other industries. *Ammonia* is produced as a by-product in the manufacture of coal gas from coke furnaces and of water gas, obtained by the passing of steam over heated anthracite with subsequent enrichment by the addition of oil. The gases thus obtained are washed to remove ammonia and tarry matters. The ammoniacal liquors are distilled to obtain the free ammonia and then treated with lime to break down the ammonium compounds, such as ammonium sulphate, thereby releasing the additional ammonia. Lime is also used in gas manufacture to absorb any sulphur or excess of carbon dioxide in illuminating gas. The *caustic alkalies*, soda and potash, are made by the treatment of sodium and potassium carbonate with milk of lime, caustic soda and caustic potash being formed with a precipitation of calcium carbonate. This is one of the few processes in which lime is used where it is not necessary to employ a lime low in magnesia. It even becomes advisable at times to use hydrate of magnesia rather than hydrate of lime, or a mixture of the two, since it is particularly serviceable in the manufacture of caustic potash. In the *purification of water* calcium hydroxide, or the hydrate of lime, is used to free the water from the soluble calcium bicarbonates. According to the action which takes place all of the lime is precipitated in the form of calcium carbonate, thereby softening the water. Milk of lime is also used to defecate the *sugar* extract in the early steps of the sugar refining, the action resulting in the neutralization of the organic acids and the coagulation of the albumen and mucus.

Hydrate of lime is also used in the manufacture of the finer qualities of glass in place of the pure limestones in order to do away with any possible ribboning of the glass through the movement of the escaping

carbon dioxide through the molten glass. Care must be used to avoid possible variations in the composition of the calcined product, due to partial hydration or contamination from the ash from the kilns.

HYDRAULIC LIMES.

Limestones containing appreciable amounts of impurities sufficient to give the calcined product hydraulic properties but insufficient to take up all the lime present are classed as hydraulic limes. They form an intermediate between simple limes and complex cements. According to their content of clayey matter they may be classified as *hydraulic* limes or as *eminently hydraulic* limes, the latter including Grappiers cements. Both are feebly hydraulic as compared with good natural cement or with Portland cement. The materials adapted for the manufacture of the poorly hydraulic limes contain small amounts of argillaceous matter and may be either calcareous or magnesian, the magnesia present acting almost interchangeably with the lime. Usually they contain from 45 to 48 per cent. of lime and magnesia, the content of the latter varying from a trace to three-quarters of the per cent. of the former, and 4 to 7 per cent. of iron and alumina, with 5 to 8 per cent. of silica. On the other hand, the eminently hydraulic limes are made from limestones that carry 39 to 45 per cent. of lime, 13 to 17 per cent. silica with alumina, and iron rarely exceeding 3 per cent. The form in which the impurities, especially silica, occur is also important, the stone improving with the degree of dissemination of the free silica and the increase in silicates. When the silica is combined less heat is required for "burning," and the fuel cost is accordingly lessened.

Both the hydraulic limes and the eminently hydraulic limes are burned in kilns very similar in type to the continuous lime kilns. The temperatures maintained in the kilns necessary to produce decarbonation is, however, higher than is required to drive off the carbon dioxide (CO_2) of non-argillaceous limestones. This is due to the presence in these limestones of their characteristic argillaceous content, which unites with a portion of the lime to form a clinker. The excess of lime which remains

uncombined is both necessary and desirable, for, by the addition of water, it slakes and disintegrates the siliceous clinker.

Compared with Portland cement or natural cement, both kinds of hydraulic limes are very feebly hydraulic. They are not manufactured in Maryland or indeed, so far as the writers are aware, in any part of America, though the materials for their manufacture certainly are not lacking. That, however, there is a demand for their use in this country is evidenced by the fact that a considerable quantity of both hydraulic lime and Grappier cements is annually imported from abroad, where the industry is one of no little importance. La Farge, the well-known non-staining cement, is a Grappier cement, and this is largely imported into America. It is probable, however, that it will be gradually replaced by the white Portland cements now made in this country. The composition of the eminently hydraulic lime, or Grappier cement rocks, vary in their content of lime from about 45 to 47.50 per cent. The silica ranges from 13 to 17 per cent., and the sum of the alumina and iron rarely exceeds 3 per cent. On the other hand, the feebly hydraulic lime rocks from which the product selenitic lime is made show a lower content of argillaceous materials. The silica runs 5 to 7.50 per cent., and the iron and alumina from 4 to 7 per cent., with a lime cement of 40 to 48 per cent. The composition of the burnt products varies, of course, with the kind of stone used, and the analyses available show that the feebly hydraulic limes contain from 65 to 80 per cent. lime, together with some magnesia, and from 7.5 to 16 per cent. silica with the iron and alumina together varying from 5+ to 12+ per cent.

Hydraulic and Cementation Index.—The combination of lime with the argillaceous impurities during burning produces a series of chemical compounds in the clinker which when ground give to the powder the property of hydraulicity or the power to set upon the addition of water. The degree to which this hydraulic power is developed depends upon the closeness of approach to the complete transformation of the burnt mass into certain definite relations with lime as the base. Formerly it was thought possible to work out an accurate classification of cements

possessing hydraulicity based on the ratio of the silica and alumina with lime according to the following formula:

$$\text{Hydraulic index} = \frac{\text{per cent. silica} + \text{per cent. alumina}}{\text{per cent. lime}}.$$

The values obtained by the use of this formula permit the tabulation of limes and cements by their hydraulic indices as follows:

HYDRAULIC INDEX.	PRODUCT.
Less than 0.10*	Common lime.
0.10-0.20	Feebly hydraulic limes.
0.20-0.40	Eminently hydraulic limes.
0.40-0.60	Portland cement (if burned at high temp.).
0.60-1.50	Natural cements.
1.50-3.00	Weak natural cements.
3.00	Puzzolans.

The term hydraulic index is merely empirical, and a great many attempts have been made to devise formulas which would express in scientific terms the hydraulic value of limes and cements. This has been unsuccessful for a number of reasons; chief of which is the fact that nearly all of these materials owe their properties not only to chemical composition but also to physical state and process of manufacture. Nearly all formulas have supposed that cements and hydraulic limes owe their hydraulic properties to definite chemical compounds. The most recent investigations which have been made upon this class of materials tend to prove that they are not definite compounds but are what are known to physical chemists as solid solutions, and are similar in character to blast furnace slags, steel, and alloys. It would seem better, therefore, to classify these compounds according to their physical properties and method of manufacture, rather than according to their chemical characteristics. Such a classification would be the following:

(1) *Common Lime*.—Limes made by burning relatively pure limestones which, when mixed with water, slake and show no hydraulic properties.

(2) *Hydraulic Limes*.—Limes made by burning impure limestones at a low temperature which slake with water, but which show hydraulic properties.

* Eckel, E. C. *Cements, Limes, and Plasters*, p. 169.

(3) *Natural Cements*.—Cements which are made by burning impure limestones at a low temperature (insufficient to vitrify) which do not slake with water, but require to be ground in order to convert them into a hydraulic cement.

(4) *Portland Cement*.—Hydraulic cements which are made by heating to incipient vitrification a mixture of argillaceous and calcareous substances, which product does not slake with water, but upon grinding forms an energetic hydraulic cement.

(5) *Puzzolan Cement*.—Cements which are formed by incorporating slaked lime with a finely ground slag or volcanic ash.

DIAGRAM OF LIMES AND CEMENTS.

Raw materials.	Chemical treatment.	Mechanical treatment.	Hydraulic or not.	Classification.
Made from relatively pure limestones.	Burned at low temperatures, 600°–1200° C.	Slake on addition of water to burned product.	Not hydraulic.	1. Common limes.
Made from argillaceous or impure limestones.				2. Hydraulic limes.
Made from an intimate mixture of argillaceous and calcareous substances in proper proportions.	Burned at high temperatures, 2500°–3000° C.	Do not slake on addition of water but must be ground finely for use.	Hydraulic.	3. Natural Roman or Rosendale cement.
Made from mixtures of slaked lime and blast furnace slag or volcanic ash.	Not burned.			4. Portland cement.
				5. Slag or puzzolan cements.

NATURAL CEMENTS.

Grouped under the name of natural cements are those products resulting from burning and subsequent grinding of the natural mixtures of calcium carbonate and clay found in the form of clayey or argillaceous limestone. Such limestones may be recognized in the field by the characteristic clayey odor that is given forth when they are breathed upon,

and on analysis in the laboratory by the fact that they carry from 13 to 35 per cent. of clayey material, of which 10 to 22 per cent. is silica. The alumina and iron oxide together may vary from 4 to 16 per cent. It is the presence of these argillaceous materials in the limestone, which may or may not also contain magnesium carbonate, that give the resulting product its hydraulic properties, but it was long thought that the presence of magnesia was equally essential. Experiment has shown, however, that this is not the case. Magnesia, when present, acts almost interchangeably with the lime, and in replacing the latter it is supposed neither to add to nor detract from the hydraulicity of the finished product.

RAW MATERIALS FOR NATURAL CEMENT.

These argillaceous limestones, from which natural cement is made, are widely distributed both geologically and geographically. During the canal-building period of the country's history they were much sought after. (Certain of the plants in Maryland were started about this time.) They have been found and manufactured into cement of more or less value in nearly every State in the Union. At present, however, the important natural cement-producing districts are comparatively few. The plants that have flourished have been those that, besides possessing abundant raw material of steady composition, located so as to be easily and economically mined or quarried, also have been favorably situated for cheap transportation, and have enjoyed the advantages of a good local market, and further have been able to obtain fuel at reasonable rates.

Of the 65 plants in the United States, reported in operation by the U. S. Geological Survey in 1903, three were located in Maryland.

An examination of the analyses of the raw materials and of the collection of products included under the name of natural cements brings out the fact (as illustrated by the analyses given further on) that the chemical composition of both the natural cement rock and the finished products varies within very wide limits. It is not surprising, therefore, that the finished products show corresponding differences both in the strength, the cementation index, and also the rate of set.

In the table of natural cement rocks below, there is presented a series of more or less typical analyses of cement rocks from seven of the more important districts in the United States.

ANALYSES OF NATURAL CEMENT ROCK.*

State	District	Silica (SiO ₂).	Alumina (Al ₂ O ₃).	Iron oxide (Fe ₂ O ₃).	Lime (CaO).	Magnesia (MgO).	Alkalies (K ₂ O, Na ₂ O).	Sulphur trioxide (SO ₃).	Carbon dioxide (CO ₂).	Water.	Cementation index.
Illinois	Utica	12.22	9.39	3.90	24.40	10.43	n. d.	n. d.	38.48		1.21
Ind.-Ky.	Louisville	9.69	2.77	1.95	29.09	15.69	n. d.	n. d.	40.14	....	0.618
Kansas	Fort Scott	21.90	3.70	3.10	35.00	3.50	....	....	33.00	....	1.68
Maryland	Hancock	19.81	7.35	2.41	35.76	2.18	n. d.	n. d.	31.74		1.68
Minnesota	Mankato	16.00	5.85	2.73	22.40	14.99	0.76	n. d.	34.11	....	1.22
New York	Rosendale	18.52	6.34	2.63	25.31	12.13	n. d.	0.90	33.31	....	1.43
Virginia	Balcony Falls	17.30	6.18	1.62	29.54	13.05	....	....	34.17	....	1.18
Average		17.24	6.05	2.16	28.06	11.51	0.76	0.90	34.98	....	1.29

* Eckel, E. C. Cement, Limes, and Plasters, Chapter xvii.

It will be seen in looking over these analyses that when an analysis from one district as compared with that of another there is, in certain instances, a considerable variation in chemical composition, and the differences in the cementation indices will also be observed. The following analysis gives the average chemical composition of the natural cement rocks from these seven different districts just referred to:

AVERAGE OF ANALYSES OF NATURAL CEMENT ROCK.

SiO ₂	17.24
Al ₂ O ₃	6.05
Fe ₂ O ₃	2.16
CaO	28.06
MgO	11.92
K ₂ O + Na ₂ O	0.76
SO ₃	0.90
CO ₂	34.98
Cementation Index	1.29

MANUFACTURE OF NATURAL CEMENTS.

In order to convert the natural cement rocks into natural cement these rocks are burned to a temperature not less than 1000° C., and for the best results between 1000° and 1100° C. In the burning process the

clayey materials are first attacked by the lime which begins to form by the decarbonation of the limestone at temperatures as low as 610° to 650° C. At 1000° C. practically all but a trace of CO_2 is driven off. After the clayey materials combine with lime near the highest and final heat of the kiln the remaining lime combines next with the more stable silicates, and lastly with free silica. The burning is done in kilns very similar to those used in burning lime. After burning, before the material is ready for sale, it has to be ground to a fine powder. The burned material is ground and packed either into sacks or bags, and is then ready for the market. The raw materials and these finished products vary greatly, in chemical composition, but their composition may be expressed only approximately, considering the variation in composition of different brands, by the typical formula $1.60 \text{ RO}, 0.23 \text{ Al}_2\text{O}_3, \text{SiO}_2$.

COMPOSITION OF NATURAL CEMENTS.

The difference in composition of natural cement rocks which has already been given is most marked and, as might be expected, there are very noticeable corresponding differences in the composition of finished products. These differences of composition are sometimes further accentuated by the conditions of burning, which not only modify the chemical composition but also produce greater or less differences in the physical properties.

ANALYSES OF NATURAL CEMENTS.*

State.	District.	Silica (SiO_2).	Alumina (Al_2O_3).	Iron oxide (Fe_2O_3).	Lime (CaO).	Magnesia (MgO).	Alkalies ($\text{K}_2\text{O}, \text{Na}_2\text{O}$).	Sulphur trioxide (SO_3).	Carbon dioxide (CO_2).	Water.
Illinois	Utica	19.89	11.61	1.35	29.51	20.38	5.96	n. d.	n. d.	....
Ind.-Ky.	Louisville	23.13	7.87	1.73	43.79	10.43	2.22	n. d.	9.28	
Kansas	Fort Scott	23.32	6.99	5.97	53.96	7.76	....	....	2.00	
Maryland	Hancock	29.74	8.34	4.14	45.66	2.86	....	....	8.13	
Minnesota	Mankato	28.43	6.71	1.94	36.31	23.89	1.80	n. d.	0.92	
New York	Rosendale	27.75	5.50	4.28	35.61	21.18	2.00	0.50	4.05	n. d.
New York	Akron-Buffalo	17.14	7.61	2.00	36.83	25.09	3.64	n. d.	n. d.	n. d.
Average		24.20	7.80	3.06	40.24	15.94				

The Maryland Natural Cements have a very high index, exceeding that of the Rosendale Cements. The Maryland Cements, moreover, are low in MgO , while the Rosendale Cements are high.

* Eckel, E. C. Cements, Limes, and Plasters, Chapter xix.

During the process of burning a unit of natural cement rock the carbon dioxide is or ought to be almost entirely driven off, and, accordingly, the percentage of argillaceous materials and calcium oxide in the cement is correspondingly increased. In the table of analyses of natural cements, this fact will be noticed as well as their differences in composition.

After natural cement rock has been sufficiently burned, the clinker is ground to a fine powder. The finer the clinker is ground the better are the results obtained. It should be ground so that 90 per cent. will pass through a 100-mesh screen. The grinding is done by suitable machinery designed for the purpose.

The cost of manufacturing natural cement varies in different localities, ranging from 20 to 50 cents per barrel, depending on local conditions.

RELATIONS OF NATURAL AND PORTLAND CEMENTS.

Natural cements are closely related both to hydraulic limes and to Portland cement. They differ, however, with respect to the hydraulic limes in that the burned mass does not slake when water is poured upon it. This is due to the fact that, in the case of natural cements, the carbon dioxide of the limestone is almost entirely driven off, and all, or nearly all of the resulting calcium oxide combines with the argillaceous materials. On the other hand, the chief points of difference between natural and Portland cements have been briefly and well summarized by Eckel * as follows:

1. Natural cements are not made by burning carefully prepared and finely ground artificial mixtures, but by burning masses of material rich in argillaceous impurities at temperatures, approximately, of 900° to 1000° C.

2. Natural cements, after burning and grinding, are usually yellow to brown in color and light in weight, their specific gravity being about 2.7 to 3.10, while Portland cement is commonly blue to gray in color and heavier, its specific gravity ranging from 3.0 to 3.2.

* Eckel, E. C. *Cements, Limes, and Plasters*, p. 195.

3. Natural cements are always burned at a lower temperature than Portland, and commonly at a *much* lower temperature, the mass of rock in the kiln rarely being heated enough to even approach the fusing or clinkering point.

4. In use natural cements set more rapidly than Portland cement, but do not attain such a high ultimate strength.

5. In composition, while Portland cement is a definite product whose percentages of lime, silica, alumina, and iron oxide vary only between narrow limits, various brands of natural cements will show very great differences in composition, while even the same brand, analyzed at different times, will show considerable differences in composition due to variations in the natural limestones used.

PORTLAND CEMENT.

Portland cement, like hydraulic lime and natural cement, is characterized by the property of setting under water which is due to certain chemical compounds produced by the burning of limestone mingled with certain impurities. Unlike the natural cements and hydraulic limes which are formed by the burning of varying natural mixtures of calcareous and argillaceous matter, Portland cement is the product of treating a carefully prepared artificial mixture of almost fixed composition. To assure the desired uniformity of composition necessitates more complicated processes of manufacture which will be described in detail in the following pages. In order that the bearing of the extended discussion of details may be clear to the average reader the general process of manufacture of Portland cement is briefly sketched.

The original mixture prepared for burning consists of calcareous and argillaceous matter in the general proportion of 2 of the former to 1 of the latter.

To assure the uniform mixture of the two substances and their chemical union during burning the raw materials are finely ground.

After these have been pulverized and mixed in proper proportions they are burned in rotary kilns at a temperature of 1600° to 1700° C., or

3000° F., to ensure incipient fusion. During the burning process the silica, alumina, and iron, which together form a large percentage of the argillaceous material with which the limestone is mixed, combine with lime and form the compounds that give this cement its peculiar hydraulic properties.

The clinker that is formed at the high temperature of the kiln is then passed through grinding and pulverizing mills and thus reduced to an impalpable buff-colored powder that has, when first ground, an average specific gravity of about 3.20. As this powder is exposed to the air the specific gravity becomes less and may fall as low as 3.00 after long storage. It is heavier than the powder of the natural cements, and on the addition of water sets more slowly but has both an early and an ultimate tensile strength that is much greater than any of the natural or rock cements.

COMPOSITION OF PORTLAND CEMENTS.*

It was the generally accepted belief for about 20 years that the essential element in Portland cement was tri-calcium silicate ($3\text{CaO} \cdot \text{SiO}_2$), and that it was to this compound that the setting and hardening properties of Portland cement were chiefly due. As to the state of the combination of alumina, however, there had been some doubt. Le Chatelier contended that the alumina was present as tri-calcium aluminate ($3\text{CaO} \cdot \text{Al}_2\text{O}_3$), while Newberry held that the alumina was present as dicalcium aluminate ($2\text{CaO} \cdot \text{Al}_2\text{O}_3$). Some 10 years ago Törnebohm, a Swedish petrographer, identified in cement, by the use of the microscope, four distinct constituents, which he called, respectively, *alit*, *belit*, *felit*, and *celit*. Alit, he stated, was the essential constituent of Portland cement and good Portland cement clinker consisted almost entirely of it. Richardson, in 1904, stated that alit was a solid solution of tri-calcium silicate in tri-calcium aluminate. In 1906, Day and Shephard stated that they had found by microscopic tests that no such compound as tri-calcium silicate existed, and that what Newberry, Le Chatelier, and

* Cf. Meade, R. K. Chemical Engineer, 1909, Vol. X, pp. 183-192.

Richardson had supposed to be this compound, was nothing more than a solution of lime in calcium ortho-silicate or dicalcium silicate ($2\text{CaO} \cdot \text{SiO}_2$). Their statements were so amply backed by proof that it is now generally agreed that Portland cement is probably nothing more than a solid solution of lime in a magma of ortho-silicates and ortho-aluminates of lime. It is, therefore, as impossible to assign to Portland cement any definite chemical symbol as it is to assign one to steel, which is a solid solution of carbon, etc., in iron or to alloys, which are also solid solutions. At the same time the composition of Portland cement has a great bearing upon its physical properties, just as does the composition of an alloy upon its physical properties. The accompanying table shows the analyses of Portland cements made from various materials and from various parts of the United States.

ANALYSES OF AMERICAN PORTLAND CEMENT.†

(Made by R. K. Meade, except those marked *.)

Made from.	Where made.	SiO ₂	Fe ₂ O ₃	Al ₂ O ₃	CaO	MgO	K ₂ O	Na ₂ O	SO ₂	Loss
Cementrock and limestone.	Nazareth, Pa.....	19.92	2.28	7.52	62.48	3.19	0.52	0.66	1.51	1.46
	Nazareth, Pa.....	21.14	2.30	6.94	63.24	3.26	0.36	0.51	1.12	1.24
	Bath, Pa.....	19.64	2.80	7.52	62.31	3.04	n. d.		1.60	1.43
	Alpha, N. J.....	21.82	2.51	8.03	62.19	2.71	n. d.		1.02	1.05
	Northampton, Pa...	21.94	2.37	6.87	60.25	2.78	0.61	0.87	1.38	3.55
	Coplay, Pa.....	22.26	2.10	5.36	63.32	3.81	n. d.		0.89	1.24
	Omrod, Pa.....	22.20	2.27	6.69	62.61	3.00	0.32	0.61	1.32	1.56
	Martin's Creek, Pa..	20.32	2.50	7.12	62.94	3.38	n. d.		1.45	1.25
	Reading, Pa.....	24.16	1.45	5.10	62.95	3.12	0.21	0.50	1.35	1.40
Limestone and clay or shale.	Bay City, Mich.....	20.74	2.85	7.17	62.64	1.97	0.48	0.12	1.42	2.58
	Wellston, O.....	21.84	5.05	6.77	62.66	0.80	n. d.		1.24	....
	Chanute, Kan.....	20.72	3.72	7.06	62.76	1.78	0.41	0.23	1.12	1.40
	Ada, Okla.....	22.28	3.20	6.36	59.66	3.11	0.80	0.25	1.40	2.82
	*Stroh, Ind.....	21.78	2.65	7.31	62.35	2.88	0.47		1.78	0.78
	*Glens Falls, N. Y...	21.50	10.50	63.50	1.80		0.40		1.50	n. d.
	Aisen, N. Y.....	23.94	3.20	5.62	62.22	1.77	n. d.		0.90	1.68
	Fordwick, Va.....	21.31	2.81	6.54	63.01	2.71	n. d.		1.42	2.01
	Davenport, Cal.....	25.38	1.20	3.84	62.96	1.20	n. d.		0.35	4.58
	Cement, Cal.....	22.34	3.30	7.00	60.72	1.30	n. d.		1.05	2.54
	*Baker, Wash.....	24.63	8.56	62.88	1.60		n. d.		1.33	n. d.
	St. Louis, Mo.....	23.12	2.49	6.18	63.47	0.88	n. d.		1.34	1.81
	Demopolis, Ala.....	19.36	4.10	9.18	63.20	1.16	n. d.		1.18	1.12
Marl and clay.	*Portland, Colo.....	21.88	2.85	7.14	64.94	Tr.	1.18		0.73	1.08
	*Middlebranch, O....	21.24	4.14	7.85	63.22	0.28	0.68		1.11	1.32
	*Coldwater, Mich....	21.22	3.33	7.51	63.75	0.82	n. d.		1.58	1.02
	Sandusky, O.....	21.93	2.35	5.99	62.92	1.10	0.63	0.27	1.55	2.92
	*Bronson, Mich.....	22.90	3.60	6.80	63.90	0.70	1.10		0.40	0.60
	*Harper, O.....	21.30	2.00	6.95	62.50	1.20	n. d.		0.98	4.62
	*Warners, N. Y.....	22.04	3.41	6.45	60.92	3.53	n. d.		1.25	.....
Limestone and blast furnace slag.	Chicago, Ill.....	22.41	2.51	8.12	62.01	1.68	n. d.		1.40	1.02
		23.06	2.88	8.16	62.10	1.88	0.36	0.58	1.57	.....

† R. K. Meade, 7th Int. Congr. of App. Chem.; see Chem. Eng., X, 185.

The composition * of Portland cement of good quality is usually within the following limits:

COMPOSITION OF PORTLAND CEMENT.

	Limits.	Average.
Silica (SiO_2)	20-24%	22.0%
Alumina (Al_2O_3)	5- 9	7.5
Iron oxide (Fe_2O_3)	2- 4	2.5
Lime (CaO)	60-63.5	62.0
Magnesia (MgO)	1- 4	2.5
Sulphur trioxide	1- 1.75	1.5

A number of theories have also been proposed as to just what takes place when cement sets. The older theories held that when water was added to the cement decomposition set in and new complex compounds of lime, silica and alumina were formed. Still another theory supposed that the cementing action was due to a network of fine needle-like crystals of calcium hydrate.

With the application of physical chemistry to the solution of problems of this character, a newer theory has been recently put forward, which supposes that when water is added to the clinker, gelatinous or colloidal silica is formed, and that this acts as a glue or jelly to bind the material together. Just at the present time the chemistry of cements is in a rather upset condition, due to the fact that we are changing from the older supposition that cement was a definite compound to the newer one that it is a solid solution, and this has effected all of our theories as to what takes place when cement hardens.

Practical experience has shown that the essential elements in cement are lime, silica, and alumina. Iron is present to more or less extent in nearly all clays and shales, and hence is always present in cement. Its presence may be looked upon, however, not simply as an impurity. It has a definite advantage; namely, it assists in burning. The white Portland cements have all proved hard to burn, and the more iron which a cement contains the easier it will burn.

* R. K. Meade. 7th Congress of Applied Chemistry; see Chemical Engineer, X, 184.

In preparing the raw materials for burning in the kiln, the best results can only be obtained when the four elements, lime, silica, alumina, and iron are mixed in the proper proportions; not only that, but the mixture should be a very intimate one, which can only be brought about by very fine grinding of the materials. The range of composition which is allowable in any given brand of cement is nowhere as large as that given in the above tables. Usually the limits for lime are not greater than 1 per cent. either way from a fixed standard, and very often they are not more than one-half of this. The composition of a given cement nearly always depends upon the index of activity, the percentage of iron and the degree of grinding which the raw materials are given.

The chemical constituents of Portland cement may be divided into two classes, the essential and the accessory. The essential constituents have already been mentioned as being lime, silica, alumina (and iron). The accessory constituents would include such compounds as magnesia, sulphuric acid, the alkalis, water, and carbonic acid, etc., which occur in the cement as unavoidable, accidental ingredients, or else as intentionally added impurities.

Essential Constituents of Portland Cements.

Lime is the most important of the essential constituents in the sense that its ratio in Portland cement to the other three essential elements is about as 2 to 1. In proportioning the mix care should be observed, therefore, to have the amount present neither too large nor too small. If the lime is in excess, the cement will be unsound—that is concrete formed from it will in time swell, crack, and possibly fall to pieces. If, on the other hand, the lime is deficient in quantity the cement will be low in tensile strength, of poor color, and often will set too quickly to allow the masons to place it in the forms. When the mixture is imperfect or the burning insufficient, the combination of the lime with the silica, alumina, etc., is incomplete, and a poor grade of cement is the result. In a Portland cement of normal composition the proportion

of lime falls within the limits, according to Chatelier,* determined by the following formulæ:

$$1. \text{ Upper limit of lime. } \frac{\text{CaO} + \text{MgO}}{\text{SiO}_2 + \text{Al}_2\text{O}_3} \geq 3.$$

$$2. \text{ Lower limit of lime. } \frac{\text{CaO} + \text{MgO}}{\text{SiO}_2 - (\text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3)} \geq 3.$$

On the whole, the greater the amount of lime that is present in cement, if it is all combined without leaving free lime, the greater will be its strength. New plants usually take advantage of this fact, and in placing their product on the market make the lime content high and burn the mixture at unusually high temperatures to obtain complete combination. As a result there is a considerable increase in the cost of manufacture, but the resulting cement is given high-testing qualities that obviously are most helpful in establishing a new brand.

The amount of *silica* in a Portland cement varies from 19 to 25 per cent. A cement with a high silica content approaching the upper limit mentioned above would imply a cement low both in alumina and iron; and conversely a cement low in silica is also generally correspondingly high in its content of alumina, and may be also high in iron. Furthermore, the high silica cements are harder to clinker than the low silica cements. They harden slowly and sometimes have trouble in meeting the short-time strength specifications, but they usually give high ultimate tensile strength. In order to avoid making a cement that will set too quickly the raw materials should be proportioned so that the silica in the resulting cement will amount to at least 2.5 times the alumina.

The amount of *alumina* permissible in a Portland cement has been given as lying between 5 and 9 per cent. Its effect upon the set of the cement is just opposite to that of silica. A cement containing from 8 to 9 per cent. of alumina is apt to set rapidly.

The tendency of high aluminous cements to set rapidly can be corrected to some extent by having the cement of low hydraulic index; that is, a high lime cement. High alumina cements are quick hardeners,

* Le Chatelier, Constitution of Hydraulic Mortars, p. 87.

and consequently cements containing from $7\frac{1}{2}$ per cent. to 10 per cent. alumina show high seven-day tests. Cements should contain at least 2.5 as much silica as alumina. This ratio between silica and alumina Meade* calls the *index of activity*. This index should lie between 2.5 and 5. Cements with an index of activity of less than 2.5 are apt to be quick-setting or else to become quick-setting on exposure to air. In order to offset this tendency to set quickly on the part of high alumina cements, it is necessary to make them relatively higher limed than those containing moderate percentages of alumina. The high lime content gives slow-setting properties which offset the quick-setting ones, due to high alumina. Cements high in alumina are hard to burn properly, owing to the fusibility of the calcium aluminate. This causes balling up and sticking together of the clinker in the hot zone of the kiln, preventing uniform burning.

Cements with an index of activity of more than five are usually very hard to burn. They are slow-setting and also slow hardeners. Their early strength is often low, but ultimately they obtain as great strength as other cements. There are a number of high silica cements on the American market which have great difficulty in meeting standard specifications as to seven-day strength.

The amount of *ferric oxide* in Portland cements is comparatively low, though it is an important ingredient. It seldom exceeds 5 per cent., and is usually below this, being generally between 2 and 4.5 per cent. It aids greatly in lowering the temperature at which the clinker is formed, and is also said to give, in replacing and lowering the amount of alumina, the cement the property of resisting the magnesium sulphate (Mg SO_4) of sea-water.

Cement made from materials containing alumina and no iron is perfectly white. It requires a higher temperature to burn, but when properly *clinkered* possesses all the setting and hardening properties of Portland cement. White Portland cements are now made at York, Pa.,

* R. K. Meade. 7th Congress of App. Chem.; see Chem. Eng., X, 187.

Canaan, Mass., and Kimmel, Ind. Below are analyses and tests of some of this white Portland cement:

ANALYSES OF SANDUSKY WHITE CEMENT, YORK, PA.

	Per cent.
Silica (SiO_2)	23.56
Alumina (Al_2O_3)	5.66
Iron Oxide (Fe_2O_3)	0.32
Lime (CaO)	64.12
Magnesia (MgO)	1.54
Sulphur Trioxide (SO_3)	1.50
Loss on ignition.....	2.92
Total	99.62

PHYSICAL PROPERTIES.

Fineness through a No. 100 test sieve = 94.7 per cent.

Fineness through a No. 200 test sieve = 76.9 per cent.

Boiling test, 5 hours = *Good*.

Initial Set = 3 hours and 45 min.

Final Set = 6 hours and 30 min.

Tensile strength 1 day neat = 333 lbs.

Tensile strength 7 days neat = 627 lbs.

Tensile strength 7 days sand = 213 lbs.

Tensile strength 28 days neat = 755 lbs.

Tensile strength 28 days sand = 246 lbs.

Iron does not make cement quick-setting and may be made to replace alumina to advantage in many cases. Portland cement in which iron replaces alumina is claimed to resist sea-water much better than ordinary cements.

Cements have been made almost entirely free of alumina and containing only lime, silica,* and iron oxide, together with the ordinary accessory impurities. These non-aluminous cements have proven in every way satisfactory when submitted to the most rigid tests. Ferric oxide has thus been shown to be able to replace the alumina entirely, though giving the cement a grayish color, but in no way diminishing its tensile strength or its hydraulicity.

A cement, called "Erz Cement," made from a siliceous limestone and iron ore is manufactured by the Krupp Steel Company, at Hemmoor,

* Meade, R. K. Portland Cement, p. 28.

Germany, and is intended for marine construction. It has about the following analysis:

Silica (SiO_2)	20.5
Alumina (Al_2O_3)	1.5
Iron Oxide (Fe_2O_3)	11.0
Lime (CaO)	63.5
Magnesia (MgO)	1.5
Sulphur Trioxide (SO_3)	1.0
Total	99.0

Accessory Constituents of Portland Cements.

Magnesia is considered the principal impurity in Portland cements. The standard specifications state that a Portland cement should not contain more than 4 per cent. of magnesia. As much as 5 per cent., however, is not thought by many of the authorities to be harmful. But all the manufacturers, nevertheless, are very careful to have the percentage of magnesia as low as possible in order to be well within the limits of the standard specifications.

Formerly it was thought that if a cement contained over 2 per cent. of MgO it was too high in magnesia, but now 4 to 5 per cent. is the allowable maximum in American Portlands and about 3 per cent. is the maximum according to foreign practice. Campbell and White, however, have shown that good Portland cements can be made, if the raw materials are carefully selected, proportioned, and burned, with a content of 10 per cent. magnesia. On the other hand, the investigation of R. Dyckerhoff, which was presented in 1895 to the German Association of Cement Manufacturers, shows that more than 4 per cent. of magnesia in the cement decreases its strength and over 8 per cent. causes it to crack.

The amount of the *potash* and *soda* present in Portland cement varies from 0 to a little over 2.5 per cent., but rarely exceeds .75 per cent. in American cements. The cements with the higher limit of the alkalies are usually made from alkali waste. The per cent. of alkalies present in the raw materials is reduced at least one-half by the heat of the kiln.*

* Meade, R. K. Portland Cement, p. 124.

A larger amount of the potash is lost and goes off with the kiln gases than soda, since the former is the more volatile. They both act as fluxes * and promote the combination of the silica and alumina with the lime. A considerable quantity of either or both of these alkalies would probably have the effect of making the cement set more quickly, since the experiment of adding to Portland cements the hydroxides of these elements has shown that they produce this result.

The *sulphur* in Portland cement is present in the form of calcium sulphate and in very small amounts as calcium sulphide. It is usually added in the form of gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) in order to retard the set. Part of the sulphur present may have been originally in the raw materials, but the amount derived from this source is generally small, most of it going off with the kiln gases in the form of SO_3 .†

The amount of *calcium sulphate* permitted by the standard specifications is below 3 per cent., or, in other words, on analysis the cement must not show over 1.75 SO_3 . This is added to Portland cement after it has been burned. In quantities below 3 per cent. the effect is beneficial, increasing both the strength and soundness of the cement. If the calcium sulphate exceeds 4 to 5 per cent. the effect is to give high short-time tests, though on the final strength test these larger amounts are found to be injurious.

The quantity of *water* and *carbon dioxide* in freshly made Portland cements is usually very small. During the process of burning both these substances are nearly or entirely driven off, and the amount remaining rarely exceeds and usually is considerably less than 1 per cent. However, as the cement is stored and allowed to season as much as 3 to 4 per cent. of carbon dioxide (CO_2) and water (H_2O) are spontaneously borrowed from the air. This relatively small amount of carbonation and hydration that occurs during the "aging" of the cement is beneficial.

The specifications place no limit on the percentage of combined water and carbon dioxide. This is because the loss on ignition gives no decisive

* Ibid., p. 30.

† Meade, R. K. Portland Cement, p. 124.

indication regarding the quality of the Portland cement, since both the carbon dioxide and the water pass off at a temperature below that of incipient fusion of the raw materials. The mass may be, therefore, under-burned and still give an ignition as low as that of a cement that has been burned sufficiently.

A complete analysis of a Portland cement will often disclose the presence of *other substances* besides those that have been mentioned. Among these are Phosphorous pentoxide (P_2O_5), Titanic oxide (TiO_2), Strontium oxide (SrO), Ferrous oxide (FeO), and Manganous oxide (MnO). They occur, however, in the commercial cements in such small amounts as to be negligible quantities, and have practically no effect on the hydraulicity or the setting properties of the cements.

When Titanic oxide (TiO_2) is present it acts like the silica for which it could probably be substituted, but not profitably, because of the greater heat that would be required to make the raw materials clinker. Manganese oxide acts, on the other hand, as a flux and, like the ferric oxide, assists in the formation of the clinker. Strontium oxide bears somewhat the same similarity to lime as the magnesia, and so when a small amount of strontium oxide is present it is not deleterious, but on the contrary acts as a base and unites with silica and alumina, and combines with ferric oxide just as lime does.

RAW MATERIALS FOR PORTLAND CEMENTS.

All the essential constituents of Portland cement are found in nature in the uncombined form as minerals, except lime, which is always combined with some other substance. Lime (CaO) combines with carbon dioxide (CO_2), forming calcium carbonate ($CaCO_3$), which occurs most abundantly as limestone. Silica (SiO_2) occurs as quartz and alumina (Al_2O_3) as corundum, while ferric oxide (Fe_2O_3), as hematite, is a prominent iron ore. Quartz is one of the chief rock-making minerals, and in the form of sandstones and quartzites occurs as a large and conspicuous part of entire mountain ranges. Quartz occurs in nature far more abundantly than hematite, and the latter in turn is much more

abundant than corundum, which is noted chiefly for its hardness, and in which respect it is second only to diamond. But because of its hardness and the difficulty of grinding, corundum is never used in cement making, and quartz and hematite are only used in very small quantities. Quartz is sometimes introduced in the form of sand or its equivalent, finely ground sandstone, to make up for a deficiency of silica in one or both of the raw materials. Small quantities of iron ore are occasionally employed for the same reason, and for the additional purpose of making a cement especially adapted for marine work.

Silica (SiO_2), alumina (Al_2O_3), and ferric oxide (Fe_2O_3), especially the first two, are essential constituents of all clays and shales and slates. They are present in greater or less quantity and more or less chemically combined, and intimately mixed mechanically in all argillaceous materials, which are so-called in reference to this fact. These argillaceous materials, such as the different varieties of clays, shales, and slates are the chief source for the silica (SiO_2), alumina (Al_2O_3), and ferric oxide (Fe_2O_3) that enter into Portland cement manufacture. On the other hand, limestone, of which there are a number of varieties, is the principal source of the lime (CaO) used.

The materials from which Portland cement is made may be divided into two major groups. The materials in which calcium carbonate is the principal constituent would be classified as calcareous, while those in which the clayey substances, silica, and alumina, are most abundant would fall under the head of argillaceous. In nature calcareous materials are found in which silica and alumina and other impurities are practically absent. There are shales and slates, on the other hand, which, if not quite, are almost wholly free from calcareous constituents. These and the pure limestones represent the extremes, between which lie calcareous shales and argillaceous limestones, which grade one into the other. When the latter is equal to or exceeds 18 per cent. in silica and alumina, it may be considered either as an argillaceous limestone or an extremely calcareous shale, but it is usually given a new name and is called "cement rock." It is customary to classify the cement rocks with the argillaceous materials.

Grouped under the head of calcareous and argillaceous for the reasons above assigned, we have the following materials:*

CALCAREOUS MATERIALS.		ARGILLACEOUS MATERIALS.
Limestones,	Cement Rock.	Clay,
Marls,		Shale,
Chalk,		Slate,
Alkali waste.		Blast furnace slag.

Calcareous Materials.

In the manufacture of Portland cement *limestone* may be combined or mixed with either clay, shale, slate, blast-furnace slag, or cement rock, and a suitable mixture obtained, provided the raw materials used are of the correct composition. The same is true of the marls, chalk, and alkali waste. Over 55 per cent. of the Portland cement manufactured in the United States is made in the Lehigh district by burning a mixture of limestone and "cement rock." In Michigan, Ohio, Indiana, and central New York the calcareous material used is marl, and this is mixed either with clay or shale, and the cement made according to the wet process, the mixture being introduced into the kilns in the form of a slurry. One plant in Michigan † formerly used caustic soda waste and clay; and in the iron manufacturing districts of Pennsylvania and Illinois the slag from blast furnaces is employed and mixed with limestone.

Outside of the Lehigh district, and the exceptions noted, a combination of more or less pure limestone and shale is the basis of the industry. These are the materials which are used by the Security Cement and Lime Company at their plant near Hagerstown, the first of the kind to be built in Maryland, and are also the ones to be employed by the Tide-water Portland Cement Company, at Union Bridge, Md.

Limestones and shales are widely distributed, and for this reason they are destined to be used in the manufacture of Portland cement even more extensively than at present. As the industry develops in Maryland they

* Meade, R. K. Portland Cement, p. 33.

† Meade, R. K. Portland Cement, p. 34.

will be the raw materials upon which the manufacturer will be chiefly dependent.

Calcium carbonate (CaCO_3), which in the crystalline form is known as calcite, is the chief constituent of limestones. When the carbon dioxide is driven off from CaCO_3 , 56 per cent. of the carbonate is left in the form of lime or calcium oxide (CaO). Limestones containing this percentage of lime, however, are exceeding rare. They are usually contaminated by such *impurities* as silica, alumina, iron, and magnesia. The last named of these four varies in amount in limestones from 0 to 21.74 per cent. When this upper limit is reached the chemical composition of the stone is expressed by the formula $\text{CaCO}_3 \cdot \text{MgCO}_3$ and is called dolomite, which contains 54.35 per cent. calcium carbonate and 45.65 per cent. magnesium carbonate.

Of the four principal impurities in limestones, *magnesia* is the most objectionable and the bane of the Portland cement manufacturer. If this substance occurs in quantities exceeding 5 to 6 per cent. the limestone becomes unsuited for use in the manufacture of Portland cement, though it may be entirely acceptable for the manufacture of lime and for other purposes. More limestones are rejected on account of the magnesia content than for any other cause. The lower, therefore, the content of magnesia the better.

The impurities, besides magnesia mentioned as occurring in limestones, are *clayey matter*, including silica, alumina, and iron. Limestones contain other impurities than these, but they occur in very small percentages, and are therefore in general negligible quantities. The percentage of iron is usually less than that of the alumina, and the sum of these two generally is less than the percentage of silica. All three are land-derived materials and owe their presence in the limestones to the fact that they were carried in suspension out to sea and were deposited, and became mixed with the calcareous muds of the latter in the form of fine silt.

The proportion in which these three substances can occur, making the limestone, so far as they are concerned, ideally suitable for manufacture into Portland cement, is when the percentage of silica equals

at least twice the sum of the percentages of alumina and ferric oxide, and the ratio of silica and alumina is between $2\frac{1}{2}$ and 4 to 1. Then, if these ratios are preserved and these clayey materials amount to 20 per cent. of the limetone, as against a content of approximately 75 per cent. of calcium carbonate, the limestone may, without the addition of further ingredients, be made directly into Portland cement.

Argillaceous limestones with the proportions of the constituents exactly as postulated above are comparatively rare. There are limestones, however, which very closely approximate the composition just described. They are not widely distributed, being chiefly confined to the Lehigh district of Pennsylvania and New Jersey, where they are known as "cement rocks," and furnish the raw material for over 55 per cent. of the Portland cement annually manufactured. Rocks closely similar in composition are also used in the West, in the states of Utah, California, and Colorado.

These limestones, and particularly the "cement rocks" of the Lehigh district, furnishing as they do the raw materials for more than half of the cement made in the United States, are worthy of a more detailed description than can be given at this point of the discussion. Their distribution, physical characteristics, and chemical composition will, therefore, be taken up later.

Silica occurs in limestone without alumina in three distinct forms. It may occur in the form of nodules of chert or flint, or in irregular veins as quartz. When a limestone contains silica in either of these forms it seriously affects the regularity of the composition of the stone and makes it practically useless for cement manufacture. Again silica may occur in a very finely divided condition and evenly distributed through the limestone, and some of it may be in the form of hydrate of silica. When this is the case it combines very readily with the lime, even though alumina be absent. And, finally, it occurs as a constituent of silicates like tremolite and diopside. This third method of occurrence is principally in the more metamorphosed limestone, the crystalline limestones, and marbles, but chiefly in the latter.

When *silica* and *alumina* occur in metamorphosed limestones they are

found combined about as they were in the clay or silt through which they were first introduced. But the same limestone, if it is considerably argillaceous after undergoing metamorphism, might have an entirely different value for cement making. For, as one of the results of metamorphism of argillaceous limestone, complicated silicate compounds are formed in which are combined both the silicon and aluminum with calcium and magnesium. In the kiln these may prove more or less inert and intractable and render the material useless. It is a matter, therefore, of the utmost concern to the Portland cement manufacturer to have the silica and alumina in the limestone properly combined, and to know in just what manner these two substances are united. The form in which they are most desired is as simple silicates of alumina more or less hydrated and finely divided and widely and evenly distributed throughout the mass. In this form the silica and alumina of the limestone, under the influence of heat, combine most readily with the lime, forming those compounds that give Portland cement its hydraulic properties. Hence it is that argillaceous limestones are much used and are considered an excellent basis for Portland cement manufacture.

Iron occurs in limestones in several different forms. It may occur as a carbonate (FeCO_3) siderite, as an oxide (Fe_2O_3) hematite, or as a sulphide (FeS_2) pyrite, and also in the crystalline limestones as a constituent in complicated silicates. It occurs commonly, however, in the form of hematite or pyrite. When the latter is present in an amount exceeding 3 per cent. the quality of the stone is seriously affected. On the other hand, the amount of ferric oxide must not be so high as to cause the ferric oxide in the cement* to be more than 4 per cent. But within these limits the presence of iron is advantageous. It acts like alumina only more effectually in promoting the clinkering of the materials and in aiding silica to combine with lime.

Among the usually negligible impurities that occur occasionally, but seldom in sufficient quantities in a limestone to have a deleterious effect, are the *alkalies and sulphur*. The former, that is, soda and potash where

* Geol. Survey of Ohio, Bull. 3, p. 226.

present, usually occur in loose-textured limestones. In amounts not over 5 per cent. they are not injurious; for then they are easily volatilized by the heat of the kiln and largely driven off with the other kiln gases. But when soda and potash exceed this limit they are apt to have injurious effects on the finished product, and the limestones, therefore, in which they are contained in amounts much over 5 per cent. are to be avoided. Limestones may contain sulphur combined as lime sulphate or gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) in considerable amounts without causing the limestone to be rejected, and cements have been successfully made from limestones containing 4 to 5 per cent. SO_3 .

The amounts of the different impurities that a limestone can contain and still remain suitable for mixing and manufacture into Portland cement may be very briefly summarized as follows:

1. The content of magnesium carbonate should not exceed 5 per cent. (or 6 per cent. where the shale to be used with it is low in magnesia), and the lower the magnesia the better. The amount in the limestone, in other words, should not be high enough to cause the magnesia in the finished product to be more than 4 per cent. This means not above 2.66 per cent. in the mixture of shale and limestone.
2. The amount of silica and alumina present should, unless present in small quantity, be in the proportion of approximately 3 of the former to 1 of the latter. However, this is not absolutely necessary, for the composition of the raw materials should be such that a slight defect here could be corrected in the mixture of limestone and shale. In a word, neither the percentage of silica nor the percentage of alumina in the limestone should be so high in the one case or so low in the other as to disturb the proper ratio that should exist between the two in the finished product.
3. The amount of ferric oxide should not be so high as to cause the amount of ferric oxide in the cement to exceed 4 per cent. except in the case of a Portland cement especially made for marine work.
4. The sum of the percentages of soda and potash, the alkalies, should not exceed 5.

5. Sulphur should be preferably low, but may even exceed 5 per cent.

6. The limestone should be fine-grained and the contained impurities should be evenly distributed which would, if this were the case, consequently give it a uniform composition.

While it is well to bear in mind the points mentioned above with regard to the impurities occurring in limestones, still it must be remembered that a limestone may fail to meet any one of the requirements just mentioned and yet be employed in the manufacture of Portland cement when used in combination with a shale that may occur nearby which supplies to the limestone what the latter lacks. Both the shale and the limestone would be abnormal but together would form a normal mixture. The proper mixture after all is the thing sought.

The second source of calcareous material, far less important than the limestone, is the *calcareous marls*. By origin and composition these fall into two groups designated according to their origin as marine and fresh-water marls. The only marls found in Maryland are of marine origin.

The marine marls, because of their contained impurities, including phosphatic matter and glauconite, are, as a rule, though not always, unsuited for use in the manufacture of Portland cement. The term marl, as used in the Portland cement industry, applies only to the fresh-water marls. These marls occur chiefly in the glaciated regions of the United States in lenticular or basin-shaped deposits of relatively small size. They consist essentially of calcium carbonate in which the impurities, silica, alumina, and iron generally occur in small quantities.

ANALYSES OF MARLS.

	Fresh Water Range *	Marine of Maryland Range.	Average
Silica (SiO_2)	1.40- 8.60	17.00-90.00	65.20
Alumina (Al_2O_3)	0.55- 1.30	0.07-10.50	4.40
Iron oxide (Fe_2O_3)	0.25- 1.54		
Lime (CaO)	54.60-46.20	3.64-42.73	20.70
Magnesia (MgO)	1.25- 2.78		
Carbon dioxide (CO_2)	42.90-36.30	2.86-33.57	9.70
Organic matter	0.05-10.50		

* Eckel, E. C. Cements, Limes, and Plasters, p. 343.

The analyses of the fresh-water marls used in this country show a high content of lime and a relatively low content of magnesia, silica, iron, and alumina. In steady practice, however, there is sometimes a considerable range in composition. This is well brought out by the analyses above (p. 293).

The analyses of fresh-water marls were compiled from material used by a prominent plant in Michigan, computed to a dry basis. As the marl comes to the plant it contains 55 per cent. or so of moisture. The analyses having been made on a dry basis, this water content in the original material is, therefore, not given. The marine marls are represented by 30 analyses from different sources in Maryland. The wide divergence in composition of the marine marls of Maryland from the fresh-water marls of Michigan clearly indicate that they are not at all suited to furnish the calcareous material for the manufacture of Portland cement. As a source of argillaceous material bearing some lime they might be mixed with the purer limestones of the adjacent Piedmont, but their low average tenor of alumina makes even such use limited to very few localities.

Cement Rock.

When the formation of limestone is in progress the fine calcareous mud, made up of shells and the comminuted tests of organisms secreting calcium carbonate, may become contaminated by clayey matter derived from the land. As a result of the terrigenous mud thus introduced and mixed with the limey mud or ooze of the accumulating limestone, materials are assembled, constituting what are known as argillaceous limestones. When the content of clayey matter equals or exceeds 20 per cent. the rock is called a "cement rock." The best known example of this is the Trenton limestone which enters into the manufacture of more than half of the Portland cement made in America, and is typically exposed and worked in the Lehigh cement district, which includes the counties of Berks, Lehigh, and Northampton in Pennsylvania, and Warren in New Jersey. The ideal material for making Portland cement is an argillaceous rock composed of approximately 20 per cent. of clayey

matter and 75 per cent. of calcium carbonate. A rock of this sort might be ground and burned and made directly into Portland cement without the admixture of any other material. A rock approaching, but not reaching, this ideal composition would, however, require the addition of pure limestone or the admixture of clayey materials, depending on whether the "cement rock" happened to be either low in calcium carbonate or low in its content of silica and alumina and ferric oxide.

Because of their softness these "cement rocks" are more easily and cheaply pulverized than the hard limestones and, moreover, form a clinker at lower temperature than mechanical mixtures of the same composition. The manufacturer using them effects, therefore, a saving both in the grinding of the raw material and in the consumption of fuel.

In the Lehigh district, where that portion of the Trenton "cement rock" * is typically exposed, it has a thickness of about 600 feet. Here it lies between a shale and a massive and more magnesian limestone. The former is known geologically as the Hudson or Martinsburg shale, and the latter as the Kittatinny limestone. The argillaceous limestone, called "cement rock," lying between the two represents a condition of shallow-water deposition during the Trenton, and like the accompanying formations is of Ordovician age. Toward its top this Trenton limestone becomes more siliceous, like the superjacent shales, while toward the bottom the lime content increases and it becomes more calcareous. In a single quarry, therefore, the beds will generally vary from argillaceous at the top to less argillaceous at the bottom.

The argillaceous "cement rock" of the Lehigh district, as may be inferred from the foregoing, is very dark gray in color and shows a characteristic slaty structure. It ranges in composition from 60 to 80 per cent. of calcium carbonate and 15 to 30 per cent. of clayey matter, and contains from 3 to 5 per cent. of magnesian carbonate. In the manufacture of cement it is generally mixed with the purer limestones

* The "cement rock" corresponds to the Chambersburg and the Kittatinny as here used to the Beekmantown and lower members of the Shenandoah group as these formations are developed in Maryland.

of the district, the right amount of the former to be added, being calculated approximately by the following formula: *

1. Quantity of limestone = $\frac{75 - \text{per cent. CaCO}_3 \text{ in cement rock}}{(\text{per cent. CaCO}_3 \text{ in limestone}) - 75} \times 100$,
or, if desired to make the calculation on the basis of the lime (CaO) content, multiply the percentages of CaCO₃, of the analyses by .56, and substitute the values in formula 2.

2. Quantity of limestone necessary = $\frac{42 - (\% \text{ CaO in cement rock})}{(\% \text{ CaO in limestone}) - 42} \times 100$.
Either of these formulas will give the amount of limestone to be added to every 100 pounds of cement rock to make the mixture approximately correct. The analyses following are fairly typical of the composition of the better grade of cement rock and the limestones of the Lehigh district with which they are mixed.

ANALYSES OF CEMENT ROCK.*

	Cement rock.			Limestone.	
	1	2	3	1	2
Silica (SiO ₂)	14.08	16.10	13.88	3.02	1.98
Alumina (Al ₂ O ₃)	7.50	2.20	6.58	1.90	0.70
Ferric oxide (Fe ₂ O ₃)	73.12	76.23	75.75	92.05	95.15
Calcium carbonate (CaCO ₃)	4.56	3.54	2.70	3.04	2.03
Magnesium carbonate (MgCO ₃)					

* Analyses 1 and 3 Cement Rock, Fred. P. Peck, *Economic Geology*, Vol. III, p. 50.

Analyses 2 Cement Rock and 1 and 2 Limestone, Ala. Geol. Survey, Bull. 8, p. 24.

Calcium carbonate may be converted to the equivalent per cent. of lime by multiplying the percentage given by .56. Also MgCO₃ may be expressed as MgO by multiplying the per cent. of MgCO₃ by 47.6.

Analysis 3 of cement rock is of an argillaceous limestone that could be burned directly into Portland cement without the admixture of either lime or shale.

Argillaceous Materials.

The principal argillaceous materials used in cement manufacture are clays, shales, and slates which have been derived from the decay of

* Meade, R. K. *Portland Cements*, p. 38.

various types of both igneous and sedimentary rocks. They are similar chemically but different in their physical character. As regards chemical composition the clays are much more irregular than either the shales or slates. Clays are composed of fine-grained, only partially consolidated, sediments which, when wet, possess the property of plasticity. These clayey sediments, of which shale and slate are indurated representatives, consist essentially of silica and alumina with accessory iron and other substances in small and varying amounts.

CLAYS.—Clays are formed in many ways and may be classified according to their origin, the more important kinds for cement manufacture being transported, residual, and glacial.

Transported clays consist of land debris which has been moved along mechanically by frost and water to stream bottoms and ultimately to the floor of the sea where they accumulate through the failure of the moving agents to transport them. Such clays are divided into alluvial clays, deposited along the banks of streams, and sedimentary clays laid down in shallow water along the sea coast.

Residual clay, aside from a small percentage of humus and transported material admixed with it at and near its surface, is derived for the most part from the decay of the solid rock upon which it rests. Its thickness, nature, and extent depend upon both the composition and physical character of the underlying rock and the amount and regularity of disintegration brought about by the various natural agencies that are constantly at work.

Glacial clays are absent in Maryland but are found in most of the northern states. They were formed under and about the front of glaciers and deposited in and along the banks of streams fed chiefly by the melting of glacier ice. To the manufacturer of Portland cement, however, they are not of very great interest because they are generally wanting in physical homogeneity and chemical uniformity.

Of the classes of clays that have been mentioned the transported clays are by far the most important. They are more uniform in composition than the residual clays and also are finer in grain and more homogeneous physically. The residual clays, no matter from what sort of rock they

are derived, generally contain, scattered through their mass, pieces of undecomposed rock of different sizes. The residual clays derived from limestones generally contain nodules of chert and small pieces of undecomposed calcium carbonate, while those derived from granite, for instance, are more likely to contain difficultly fusible minerals like quartz.

The difference in composition of the transported and residual clays is due to the difference of origin and to the further fact that the transported clays are derived largely from the residual clays. The former contain finer and more uniform particles resulting from the reworking of the residual clays into branches, creeks, and rivers, and the subsequent separation of the coarse and fine material by the sorting action of running water.

A clay to be suitable for use in the manufacture of cement should be homogeneous physically, fine-grained, and of correct and uniform composition throughout. The presence of sand and of nodules of various sorts, particularly flint and quartz, if present to any considerable extent, are extremely objectionable and may make an otherwise acceptable deposit altogether worthless.

The clay for Portland cement manufacture should contain at least 55 per cent., but preferably between 60 and 70 per cent., of silica. It should be low in magnesia and alkalies, preferably not over 3 per cent., and low in sulphides or sulphur. Clays may often contain considerable magnesia without rendering them unfit for use in cement manufacture, particularly when they are to be used with limestones low in magnesia. They should not contain too much iron, and usually this should not be more than one-third of the alumina. The sum of the percentages of alumina and iron should not be more than one-half the percentage of silica, and the clay will usually be better the nearer the percentage ratio $\frac{\text{SiO}_2}{\text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3} = 3$ is approached.

Clays are divided into "normal" and "limey" clays according to their content of magnesia (MgO) and lime (CaO). If the sum of these oxides exceeds * 5 per cent. the clay is called a limey clay, and if it

* Eckel, E. C. Cements, Limes, and Plasters, p. 354.

contains less than 5 per cent. of lime and magnesia it is referred to as a normal clay. Below are given a number of analyses of both normal and limey clays actually used in Portland cement manufacture:

ANALYSES OF NORMAL AND LIMEY CLAYS USED IN THE MANUFACTURE OF PORTLAND CEMENT.

	Normal Clays.*			Limey Clays.		
	1	2	3	1	2	3
Silica (SiO_2)	53.30	63.82	57.25	55.27	47.45	61.70
Alumina (Al_2O_3)	23.29	25.36	26.15	10.20 3.40	19.85	18.00
Ferric oxide (Fe_2O_3)	9.52					
Lime (CaO)	0.36	3.42	3.09	9.12	17.80	8.40
Magnesia (MgO)	1.49	n. d.	1.10	5.73	0.09	2.91
Alkalies ($\text{K}_2\text{O} + \text{Na}_2\text{O}$)	n. d.	n. d.	1.88	n. d.	4.34	n. d.
Sulphur Trioxide (SO_3)	n. d.	n. d.	0.39	n. d.	1.03	n. d.
Carbon dioxide (CO_2)	n. d.	6.96	9.30	n. d. n. d.	n. d. n. d.	13.30
Water (H_2O)	n. d.					
SiO_2	—	—	—	—	—	—
$\text{Fe}_2\text{O}_3 + \text{Al}_2\text{O}_3$	1.62	2.52	2.19	4.06	2.39	3.43

1. White Cliffs Portland Cement Company, White Cliffs, Arkansas.

2. Peninsular Portland Cement Company, Cement City, Michigan.

3. Pacific Portland Cement Company, California.

1. Sandusky Portland Cement Company, Syracuse, Indiana.

2. Buckeye Portland Cement Company, Harper, Ohio.

3. Wabash Portland Cement Company, Stroh, Indiana.

* Eckel, E. C. Cements, Limes, and Plasters, p. 355.

SHALES AND SLATES.—*Shales* and *slates* have, as has been noted, essentially the same composition as clays, that is, the chief and important constituents are silica, alumina, and iron, with varying small amounts of other substances. Except in the manufacture of Portland cement from marls by the wet process, shales and slates are, on the whole, preferred to clays, even though they are harder.

Like the clays, both shales and slates vary widely in chemical composition, but within a limited area they show as a general rule a much greater homogeneity than clays do, and also much more uniformity in chemical composition. This is due primarily to their difference in origin.

The hardness and fissility, characteristic of shales, are due to the pressure to which the original unconsolidated clayey sediments were subjected subsequent to their deposition. The same sort of sediments, as the result

of metamorphism, may be changed to slates which differ from the shales not only in their greater and more perfect fissility, but in the further fact that the cleavage is a secondary property which may or may not be parallel to the planes of stratification.

Because of their wider occurrence and their more favorable situation, with respect to limestones, shales are far more extensively used in Portland cement manufacture than slates.

The term shale, as popularly used, refers to a rock with more or less marked cleavage, fine-grained and uniform in composition, consisting essentially of silica, alumina, and iron, in variable proportions. For example, there are shales high in silica, the so-called siliceous shales, and then again there are those high in iron and alumina, etc., besides which there are also calcareous shales, containing an exceptional amount of lime, and carbonaceous shales characterized in certain exceptional instances by the presence of as much as 12 to 14 per cent. of carbon.

Shales, however, to be used in the manufacture of Portland cement must meet certain clearly defined specifications with regard to chemical composition. These are briefly enumerated as follows:

They should be preferably low in magnesia, and should not exceed in any case an amount which would cause the content of magnesia in the cement to be greater than 4 per cent.

The ratio of silica to alumina should be between 2.5 to 1 and 4 to 1.

The content of sulphur should be preferably low, not exceeding 5 per cent.

The shale should also contain at least 3 per cent. of ferric oxide for fluxing purposes, but not enough to cause the ferric oxide in the cement to exceed 4 per cent. The nearer the ratio

$$\frac{\text{SiO}_2}{\text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3} = 3$$

is approached the better is the quality of the shale. There should be at least 55 per cent. of silica, but preferable between 60 and 70 per cent.

To clays or shales which are slightly low in silica and high in alumina the ratio between the two may be corrected often by the addition of small amounts of finely ground sandstone or sand. Likewise if it is

slightly low in ferric oxide this may be added in the form of the iron ore, hematite.

The shale may be absolutely abnormal, however, and still prove satisfactory if the limestone with which it is to form a mixture has such a composition that in its abnormality it supplements and remedies the defects in the shale or slate, the two forming a normal and correctly proportioned mixture fit for burning into Portland cement.

Below are given the analyses of some of the shales used in different American cement plants, including the normal shales, where the sum of the lime and magnesia is less than 5 per cent., and the limey shales, where the content of the two is higher than the figure just mentioned:

ANALYSES OF SHALES USED IN THE MANUFACTURE OF PORTLAND CEMENTS.

	Normal Shales.*				Limey Shales.			
	1	2	3	4	1	2	3	4
Silica (SiO_2)	60.00	59.64	65.99	54.70	53.12	57.45	57.50	53.63
Alumina (Al_2O_3)	23.26	19.14	21.57	31.68	20.60	20.56	21.70	24.47
Ferric oxide (Fe_2O_3)	4.32	7.59	6.07		4.09	2.78		
Lime (CaO)	0.90	0.26	0.47	1.15	4.02	4.27	12.19	5.94
Magnesia (MgO)	1.12	2.31	0.82	n. d.	2.24	3.17	1.93	1.79
Alkalies ($\text{K}_2\text{O} \cdot \text{Na}_2\text{O}$)	n. d.	4.33	n. d.	n. d.	....	....	....	....
Sulphur trioxide (SO_3)	n. d.	n. d.	n. d.	n. d.	n. d.	0.35	n. d.	n. d.
Carbon dioxide (CO_2)	6.16	4.71	n. d.	n. d.	13.70	8.15	n. d.	10.03
SiO_2	2.14	2.23	2.38	1.72	2.15	2.45	2.65	2.19
$\text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$								

1. Ironton Portland Cement Company, Ironton, Ohio.

2. Lehigh Portland Cement Company, Mitchell, Indiana.

3. Crescent Portland Cement Company, Wampum, Pa.

4. Hudson Portland Cement Company, Hudson, N. Y.

1. Chicago Portland Cement Company, Oglesby, Ill.

2. Alpena Portland Cement Company, Alpena, Mich.

3. Cayuga Portland Cement Company, Portland Point, N. Y.

4. Virginia Portland Cement Company, Craigsville, Va.

* Eckel, E. C. Cement, Limes, and Plasters, p. 357.

LOCATION OF A PORTLAND CEMENT PLANT.

The following factors have to be considered in locating a cement plant or any industrial enterprise dependent on the use of either limestone or shale, or the use of them both together:

1. Location of deposit, with respect to transportation routes and markets.
2. Amount of material available.
3. Chemical composition of material.
4. Fuel supply.

Location with Respect to Transportation Routes and Markets.

One of the first factors influencing the location of a proposed cement plant is its relation to transportation routes and markets. Unless the proposed site is near a railroad or water route along which the necessary raw materials and finished products may be moved economically all profits of manufacture are likely to be absorbed in meeting the prices of competing concerns more favorably situated. To acquire satisfactory freight rates it is necessary to select sites near friendly transportation lines or where low rates may be secured through the competition of rival carriers. The distance from large and well-established markets is another prime factor, since for its value Portland cement is a heavy and rather bulky commodity. The margin between cost of manufacture and selling price may easily be absorbed by the increased freight charges involved in long haulage.

Location with Respect to Raw Materials.

In searching for a limestone intended for the manufacture of Portland cement, a great amount of preliminary information may be had from the reports that have been issued by the Maryland Geological Survey and the Federal Government. The prospector before starting out should obtain, therefore, all the data available from these sources and take into the field, provided they are to be had, both topographic and geological maps of the region in which suitable material is sought. The geological maps will show the areal distribution of formations, and the reports will give their thickness and more or less information as to the quality of the materials of which they are composed. The maps will further show the relations of shales and limestones which should occur near one another, and the occurrence of both with regard to water, transportation facilities,

etc., and distances from the leading markets. From these facts the investigator, be he a geologist, mining engineer, or even an untrained prospector acting for himself, or another, may decide in what particular district it would probably be best to locate and where detailed work may be pursued with the best chances of finding sufficient material of a composition suitable for the purpose.

One can hardly expect, however, to find in geological reports the detailed information as to the quantity and the quality of material occurring within the limits of any particular property. The presentation of the facts in these reports must necessarily be more or less general. Information of the sort that is required before the investor would be justified in making a purchase must be had, therefore, by employing either a first-class geologist, chemist, or mining engineer, to make an examination and render an opinion, together with the facts upon which it is based.

DETERMINATION OF QUANTITY.—In determining the available quantity of limestone or shale the first step is to measure its thickness, not along the surface of outcrop, but along a line perpendicular to the planes of stratification, or, in other words, perpendicular to the direction of dip. In Figure 17, for instance, the limestone is overlain by shale and the direction of the dip is represented by the line *EH*. The thickness should, therefore, be measured along the line *EG*, which is equal to the sum of the thicknesses of the individual beds between *G* and *H*. The thickness of the limestone bed represented in Figure 18 is equal to *AB*, less the thickness of the soil covering, but if a ravine or railroad cut should expose the stone along *CD* the thickness would be obtained by measuring along this exposure perpendicular to the bedding; or the same value could be computed by multiplying the distance measured along *CD* by the natural sine of the angle between *CD* and the horizontal. With the thickness thus obtained, and a knowledge of the direction of the strike, it becomes an easy matter to calculate the quantity of material. If, for instance, a limestone bed 200 feet thick outcrops and can be traced for a distance of 2500 feet across a certain property and can be worked to a depth of 100 feet, along the dip the number of available cubic feet of

stone is obtained by multiplying these values. A cubic foot of limestone is taken at 160 pounds, and therefore the value in pounds would be $200 \times 100 \times 2500 \times 160$. This product, divided by 2000 would give the value in tons which in this case would amount to 4,000,000 short tons, or enough material to last a five-kiln Portland cement plant for over 50 years, each kiln consuming yearly close to 15,000 tons of limestone. About one-third this amount of shale, or 5000 tons per kiln, would have to be provided for annually to mix and burn with the limestone. In order to have the supply of shale last for as long a period as the limestone, the shale property should contain about 1,500,000 tons of shale, all of which should be, like the limestone, susceptible of economic quarrying. The quantity of shale is calculated as the tonnage of limestone was, with the exception that the shale is estimated as weighing less than the limestone, or from 125 to 130 pounds per cubic foot.

Before a Portland cement plant is located there should be sufficient raw material in sight to ensure an unfailing supply for a period of at least 25 years, estimating the capacity of the plant at from 2000 to 2500 barrels a day. The tonnage of shale and limestone required may be estimated approximately from the table below, taken from "The Lime and Cement Resources of Missouri," by H. A. Buehler. As stated by the author the table was compiled to show "the *approximate* number of acres of shale and limestone required to supply a Portland cement factory having a capacity of 2500 barrels per day." It is obvious, of course, as the compiler of the table observes, that the values given are only and can be only approximate, because of the varying quantity of limestone and shale that enter into different mixtures ready for burning.

As stated elsewhere in this report, both the shale and limestone may be abnormal, and yet mixed in proper proportions with due regard to the chemical composition of each, yield a mixture which would burn to a clinker that may be ground into a cement capable of meeting the most rigid requirements. The figures given in the table below are based on statistics gathered in Missouri where "an average of 132 pounds of shale and 465 pounds of limestone are used to produce a barrel

ACRES OF LIMESTONE AND SHALE REQUIRED FOR A 2500-BARREL PLANT.*

Thickness.	Deposit.	10 yrs.	15 yrs.	20 yrs.	25 yrs.	30 yrs.	35 yrs.	40 yrs.	50 yrs.	60 yrs.	75 yrs.	100 yrs.
5 ft.	Shale	36.9	55.3	73.7	92.2	110.6	129.0	147.5	184.3	221.2	276.6	368.7
5 ft.	Limestone	116.0	174.0	232.0	289.9	347.9	405.9	463.9	579.8	695.8	869.7	1159.6
10 ft.	Shale	18.4	27.7	36.3	46.1	55.3	64.5	73.7	92.2	110.6	138.3	184.3
10 ft.	Limestone	58.0	87.0	116.0	141.0	173.9	203.0	232.0	289.9	347.9	434.9	579.8
15 ft.	Shale	12.3	18.4	24.6	30.7	36.9	43.0	49.2	61.5	73.7	92.2	122.9
15 ft.	Limestone	38.7	58.0	77.4	96.7	116.0	135.3	154.7	193.3	232.0	289.9	386.6
20 ft.	Shale	9.2	13.8	18.4	23.1	27.7	32.2	36.9	46.1	55.3	69.2	92.2
20 ft.	Limestone	29.0	43.5	58.0	72.5	87.0	101.5	116.0	145.0	173.9	217.5	289.9
25 ft.	Shale	7.4	11.1	14.7	18.4	22.1	25.8	29.5	36.9	44.3	55.3	73.7
25 ft.	Limestone	23.2	34.8	46.4	58.0	69.6	81.2	92.8	116.0	139.2	173.9	232.0
30 ft.	Shale	6.1	9.2	12.3	15.4	18.4	21.5	24.6	30.7	36.9	46.1	61.5
30 ft.	Limestone	19.4	29.0	38.7	48.4	58.0	67.7	77.4	96.7	116.0	145.0	193.3
40 ft.	Shale	4.6	6.9	9.2	11.6	13.8	16.1	18.4	23.1	27.6	34.8	46.1
40 ft.	Limestone	14.5	21.8	29.0	36.3	43.5	50.8	58.0	72.5	87.0	108.8	145.0
50 ft.	Shale	3.7	5.5	7.4	9.2	11.1	12.9	14.7	18.4	22.1	27.7	36.9
50 ft.	Limestone	11.6	17.4	21.2	29.0	34.8	40.6	46.4	58.0	69.6	87.0	116.0
60 ft.	Shale	3.1	4.6	6.1	7.7	9.2	10.8	12.3	15.4	18.4	23.1	30.7
60 ft.	Limestone	9.7	14.5	19.4	24.2	29.0	33.9	38.7	48.4	58.0	72.5	96.7
70 ft.	Shale	2.6	4.0	5.3	6.6	7.9	9.2	10.6	13.2	15.8	19.8	26.3
70 ft.	Limestone	8.3	12.9	16.6	20.7	24.9	29.0	33.2	41.4	49.7	62.2	82.8
80 ft.	Shale	2.3	3.6	4.6	5.8	6.9	8.1	9.2	11.6	13.8	18.4	23.1
80 ft.	Limestone	7.3	10.9	14.5	18.2	21.8	25.4	29.0	36.3	43.5	58.0	72.5
90 ft.	Shale	2.0	3.1	4.1	5.1	6.1	7.2	8.2	10.3	12.3	15.4	20.5
90 ft.	Limestone	6.5	9.7	12.9	16.1	19.4	22.6	25.8	33.0	38.7	48.4	64.5
100 ft.	Shale	1.8	2.7	3.7	4.6	5.5	6.4	7.4	9.2	11.1	13.8	18.4
100 ft.	Limestone	5.8	8.7	11.6	14.5	17.4	20.3	23.2	29.0	34.8	43.5	58.0

* Missouri Bureau of Geology and mines, "The Lime and Cement Resources of Missouri," by H. A. Buehler, Vol. VI, 2d. ser., p. 46.

The area given is for horizontal beds. If the strata are folded or inclined the figures apply to the areas of the respective beds between their surface outcropping and the depth of economical quarrying, since the latter figure seldom exceeds 100 feet the area of surface ground underlain will differ with the inclination of the beds decreasing rapidly with the increase in dip.

of Portland cement." * The weight of a cubic foot of limestone is taken at 168 pounds, and the weight of a cubic foot of shale is taken at 150 pounds. Both these weights appear to be rather high, particularly that quoted for a cubic foot of shale.

The reader is cautioned against putting too much reliance on a table like the above, except as indicated, i. e., to obtain approximate values. The only means of knowing the amount of limestone and shale needed in any particular case is from the chemical composition of both.

Examinations of limestone and argillaceous deposits soon disclose the fact, that when the two are sought for use in the manufacture of Portland cement, it is much more difficult to find deposits of the former having the correct chemical composition than it is to locate a suitable shale. This is because most of the limestones contain more than the permissible amount (5 to 6 per cent.) of magnesia. Limestones low in magnesia are scarce, and large deposits suitably situated and of the proper composition for making Portland cement are rare enough to make them "as valuable as a good iron ore deposit."

When shales and limestones are used in Portland cement manufacture about 75 per cent. of the mixture consists of limestone which is composed essentially of calcium carbonate. If the limestone contains a considerable percentage of clayey matter it may be necessary to add a purer limestone, and conversely, if the limestone is very pure there must be a proportional increase in the mixture of argillaceous limestone or of those materials composed essentially of silica, alumina, and iron, such as clays, shales, etc. In selecting properties to furnish the raw materials for a cement plant, provision must be made for a tonnage of limestone amounting to about three times that of the shale. Thus, to reiterate, limestone is the principal and controlling ingredient of the cement mixture. Therefore, in choosing a site for a cement plant which consumes about three times as much limestone as shale, the first and most important step is to find an area where the limestone of suitable composition is present in abundance. If the limestone and shale should happen

* Buehler, H. A. The Lime and Cement Resources of Missouri, p. 45.

to be some distance apart, the plant should be located on the property containing the former.

DETERMINATION OF QUALITY.—In the search for a property of the sort just mentioned one will encounter property after property where limestone occurs in abundance and suitably situated which is unacceptable because the limestone is too high in magnesia.

That the search for suitable material may progress rapidly and the cost of chemical analyses be lowered to a minimum, it becomes necessary to eliminate such properties as fast as possible. This can be accomplished if some inexpensive and sufficiently accurate method is employed in the field that will indicate the relative content of magnesia in the various limestones encountered.

Limestones containing 15 to 20 per cent. of magnesia may be detected by the fact that when treated with acid they effervesce and give off carbon dioxide (CO_2) less freely than limestones in which the content of magnesia is somewhat less than the amounts mentioned. While this method of determining magnesian limestone is good enough as far as it goes, it fails to go quite far enough. Cement specifications call for limestones in which the magnesia (MgO) content is not over 0.2 to 3.5 per cent. and, therefore, a more accurate method is desirable. Such a field method was worked out by Mr. J. J. Porter, Associate Professor of Metallurgy at the University of Cincinnati, when employed as an assistant in the laboratory of Mr. Charles Catlett, of Staunton, Virginia, and is given below:

FIELD TEST FOR MAGNESIA.

THEORY.

This method is based on the fact that while calcium hydrate is very soluble in a solution of cane sugar, magnesium hydrate is only slightly so. This gives us a means of precipitating magnesia in the presence of lime, obviating the necessity of a tedious preliminary separation of lime.

Iron is removed from the solution by boiling with an excess of pure calcium carbonate by which it is precipitated as a hydrate, so that it can be filtered off with the insoluble matter. If left it would be held in solution by the sugar, but the color would be a disturbing influence. As ammonia salts have a strong solvent action on magnesia hydrate, soda or potash is used as the precipitant, and this also serves the purpose of holding the alumina in solution.

Manganese and zinc, if present in large amounts, will interfere slightly. Their hydroxides are redissolved by soda and sugar, but slowly, and a noticeable turbidity usually remains. Barium also gives a turbidity, probably due, however, to traces of sulphates in reagents. These elements, as well as others which might interfere, rarely occur in more than minute traces in limestone, so that the value of this test for technical work is unaffected.

REAGENTS.

1: 1 Hydrochloric acid. One volume hydrochloric acid of 1.20 specific gravity plus one volume of water.

A 30 per cent. solution of sodium hydrate. Thirty grams of sodium hydrate (pure by alcohol) to 100 cc. of water. This must be free from carbonate.

Sugar solution. A cold saturated solution of granulated sugar.

Calcium carbonate c. p. precipitated.

Standard limestones as needed, powdered to 40 mesh.

APPARATUS.

A small steel mortar for powdering samples.

Small sieve, 40 mesh.

Measuring spoon, holding between .4 and .5 grams of 40 mesh limestone powder, level full.

Twelve test tubes with mark at 10 cc.

Stand to hold 12 test tubes in two rows.

A pipette, $1\frac{1}{2}$ cc., for sugar solution.

A pipette 1 cc., for sodium hydrate.

Six small funnels.

Filter papers to fit, uniform size.

Test tube holder.

Alcohol lamp.

Water bottle.

Test tube brush.

All of the above apparatus may be packed in a small box having inside dimensions of 11" x 7" x 7".

METHOD.

Crush and powder sample in mortar and sift. Pour this powder into a measuring spoon and level off by knife blade or card. Transfer the measured portion to test tube.

Add now from pipette $1\frac{1}{4}$ cc. of acid, and when effervescence has nearly ceased, boil for a moment. Add next sufficient of the pure calcium carbonate and neutralize the excess acid. Boil until steam issues freely from the mouth of the test tube in order to drive out all the carbon dioxide. Add water to the 10 cc.-mark and mix thoroughly by shaking the test tube.

In another test-tube place by means of the proper pipettes $1\frac{1}{2}$ cc. of sugar solution, 1 cc. of sodium hydrate solution and dilute with water to the 10 cc.-mark. Then filter the solution of the stone allowing the filtrate to run in the alkaline sugar solution. If magnesia is present a precipitate of magnesium hydrate will form at the line of contact of the two solutions, and

after the filter has drained these solutions should be mixed by inverting the test tube.

The density of this precipitate is roughly indicative of the percentage of magnesia in the stone, and by comparison with standard stones run in parallel this percentage can be estimated fairly accurately, the probable error not being greater than 20 per cent. of the amount of the magnesia present.

NOTE AND PRECAUTIONS.

The fineness of the stone affects the weight held by the measuring spoon and also the ease of solution, hence the need of sifting.

There should be sufficient acid to dissolve thoroughly all the carbonates of the stone and this condition is assured if the resulting solution is yellow from ferric chloride. At the same time it is desirable to have the smallest possible excess of acid, since the presence of alkaline chlorides decreases very materially the delicacy of the test.

The object of the calcium carbonate is twofold. It precipitates the iron, and it creates a condition of uniformity as to the neutrality of the solution which is very essential for comparative results.

It is desirable that all the filter papers used in a series of tests be of uniform size and quality of paper, so that they may retain a uniform amount of the stone solution.

The method of adding the reagents is important and it should be closely followed.

Sugar has a much greater influence in preventing the precipitation of magnesium hydrate than in dissolving it after it has formed, and if the sugar be added to the stone solution before the alkali, the delicacy of the test is very much lessened.

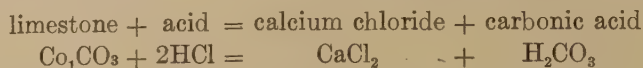
After trying all sorts of methods the one given above has been found to give the most satisfactory results, both as to delicacy and reliability.

It is of course essential that the sodium hydrate contain no carbonate, and it should, therefore, be occasionally tested by barium hydrate or by a solution of lime and sugar.

The magnesium hydrate precipitate frequently comes down of a greenish color. The cause of this I have been unable to determine, but it is most prominent in those samples containing carbonaceous organic matter. Possibly it is due to a trace of ferrous iron produced by the carbonaceous matter. This color apparently causes the precipitate to appear somewhat more dense and opaque, and therefore should be allowed for in making comparisons. With a little practice this is not difficult, particularly if the comparison is made by transmitted light.

With the procedure outlined above the best conditions for comparison are obtained from stones ranging up to 4 per cent. magnesia. Percentages above this give a precipitate so dense as to make comparison very difficult and uncertain. Dilution to a larger volume before comparison is of great assistance in these cases, but if much work were to be done exclusively on high magnesia samples, it would be preferable to filter off an aliquot part (one-half or one-fourth) of the stone solution.

Pure limestone, when treated with dilute hydrochloric acid, will disintegrate entirely and pass into solution according to the reaction:



The carbonic acid breaks down to water and carbon dioxide. It is this reaction, $\text{H}_2\text{CO}_3 = \text{H}_2\text{O} + \text{CO}_2$, that causes the effervescence that is observed when limestones are touched by or immersed in certain dilute acids, particularly hydrochloric.

If a splinter of limestone is put into a test tube and effervesces, and then effervescence ceases without dissolving all of the calcium carbonate as a result of a precipitate or coating forming on the splinter, it indicates that if this limestone is used it must be mixed with one higher in its content of calcium carbonate. On the other hand, if all the calcium carbonate is dissolved from the splinter of stone and the latter still retains approximately the outline of its former shape, the limestone is probably very close to being what is commonly known as "cement rock," requiring before burning the addition of very little, if any other, material.

The limestones high in magnesia can be distinguished to a certain extent by their physical appearance. Not only are they slightly harder and less easily weathered than the limestones in which the content of magnesia is low or entirely absent, but on fresh fracture they have a duller luster, a rather saccharoidal texture, and present a coarser, less smooth, and less fine-grained surface. Broadly speaking, the low magnesian limestones (2 to 5 per cent. MgCO_2) have a satiny luster, while the luster of the high-magnesian limestones is less marked. This is particularly true of the Shenandoah limestones of the Hagerstown and Frederick valleys, but is a rough diagnostic that is of no value whatever in the Piedmont, where the physical appearance of the limestone is quite different. The limestones of the Piedmont are dominantly white and crystalline, while the Shenandoah are less crystalline and vary in color from blue and gray to a light dove color. The magnesia, when the content in the Piedmont limestone is high, is often evidenced by the

presence of the mica, phlogopite, which is one of the numerous minerals found in crystalline limestones as the result of metamorphism.

SAMPLING AND DRILLING.—The manufacture of cements, particularly Portland cement, is a strictly chemical process, as much so, and in the accuracy of its details almost more so, than the manufacture of iron. Therefore, it is extremely essential that the substances used should have not only a uniform composition, but should have a composition that fulfils all the chemical requirements. Hence, in locating a site for a plant, the materials to be used should be sampled with the greatest care. The whole success of the undertaking depends upon the care and manner and accuracy with which this is done.

The samples should be taken so that every inch of the rock to be employed will be represented in the sample. These should be taken perpendicular to the bedding, though this is not necessary if every bed is sampled at the same angle. However, the first method is easier and accompanied by less danger of error. Samples might be taken by some mechanical means, such as drilling, by which each bed would be sampled at the same angle, but in the work of preliminary examinations this would involve a large, and oftentimes unnecessary, expense. If the beds, however, should happen to be horizontal, or approximately horizontal, and not shown anywhere in vertical section on the particular property under examination, then drilling would be the only proper and possible course of getting samples.

There is a widespread impression, however, that every property upon which a cement plant is to be located should be and can only be thoroughly sampled by diamond drilling. This is due largely to the misleading statements that have appeared in many of the various cement company prospectuses, but to a certain extent is due also to the manner in which some writers on the subject have unduly emphasized the accuracy of this particular method of sampling as against all others.

It seems, therefore, not out of place in this connection to show those geological conditions which demand drilling, and those where it is unnecessary, and where a cheaper and sufficiently accurate method may be substituted in its stead.

The two drawings on this page show in the case of Figure 17 horizontal strata, and in the case of Figure 18 strata that have been considerably tilted. The thickness of the limestone in both cases is obtained by measuring perpendicular to the bedding. In general, limestone occupy-

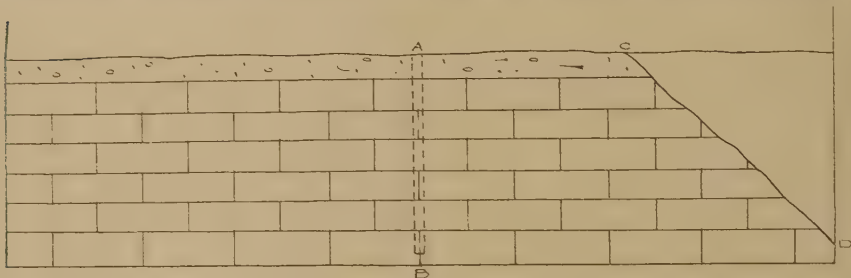


FIG. 17.—Diagram showing method of determining thickness of horizontal beds.

ing the horizontal position shown in Figure 17 could only be sampled by use of the diamond drill, while that inclined and dipping from the horizontal as seen in Figure 18 might be sampled without going to this extra expense.



FIG. 18.—Diagram showing method of determining thickness of inclined beds.

The necessity of drilling for samples in horizontal strata only arises when the horizontal strata on a particular property are not shown in vertical section, or where such vertical sections are poorly exposed. The usual vertical section may be furnished by a railroad cut or, to even better advantage, by the erosive agents of nature. A stream cutting through the property might reveal the rock along the line *CD*. A series

of samples taken along this stream-cut section, representing the various beds exposed, would be fairly indicative of the quality of the stone as a whole. Nevertheless it would be advisable and necessary before reaching a final decision to take other samples up and down the stream along sections parallel to *CD*, and at intervals of 30 to 50 feet.

If the chemical constituents of the stone, as exhibited by the analyses made on these samples, showed a very narrow range, and the analyses were otherwise satisfactory, it would lead to a very strong presumption that the stone throughout the property was uniform in chemical composition. A presumption supported by such facts as these is usually borne out by experience, but it is doubtful whether a limited amount of drilling could safely be dispensed with on a property with horizontal strata dissected by only one stream.

In Figure 18 are shown tilted strata dipping at an angle of about 30 degrees. Overlying the limestone is shale, and both are represented in the conventional manner used in geological drawings. Either of the formations could be sampled at the surface by removing strips of such surface covering as may be present in the form of transported or residual soil, provided the overburden is not sufficient to make their subsequent exploitation unprofitable.

Figure 18 illustrates also how a great deal of useless drilling is often done to discover at various depths what may be clearly seen at the surface. For instance, a drill hole sunk along the line *EF* would pass through a stratigraphic thickness equal to *KF*. The bed *F* projects and may be observed at the surface at a distance from *E* opposite to the direction of dip equal to $\tan (90 - \alpha) EF$, where α is equal to the angle of dip. It may be observed here that the steeper the dip the less is the stratigraphic thickness gone through for each foot of drilling. When the strata are on end, or dipping at 90 degrees the stratigraphic thickness passed through is, therefore, only equal to the diameter of the drill. In such a case, and numerous instances are known where drilling has been done both on a vertical and approximately vertical strata, the money spent has been absolutely wasted.

Sampling a Portland cement property where the strata are more steeply inclined may be accomplished by the use of a diamond drill, but this entails, as has already been pointed out, a considerable expense. Drilling along the line *EF* the stratigraphic thickness gone through at a depth *F* is equal to *KF* and $KF = \cosine \text{ of the angle } KFE \text{ by } EF$. This same thickness might be just as well sampled by trenching along the surface and sampling perpendicular to the bedding for a distance equal to $\tan (90 - \alpha) \text{ by } EF$.

If the strata should happen to be exposed along the line *GH* samples could and should be taken perpendicular to the bedding at intervals of from 30 to

50 feet, or even closer and parallel to *EG*, which is drawn at right angles to the dip. In other words, under such conditions each individual bed should be sampled. The bed marked *L* might be sampled perpendicular to the bed at the point *L* (see Fig. 18) while stratigraphically and immediately below the bed marked *M* might be hidden by talus or soil. A sample of this bed taken perpendicular to the strata might, however, be had at the point *M* 30 to 50 feet from *L* where the bed *M* happened to be exposed. Likewise, another sample might be taken of the bed *N* at the point *N* and so on at convenient points of each separate bed down to *G*. These samples on analysis would furnish a basis of comparison of the quality of the stone down the dip. Should they prove approximately uniform and show a narrow range in composition, it may be fairly expected that the composition at different intervals along the strike that show a corresponding uniformity, and conversely, samples taken along the strike that show a uniform composition in this direction indicate within reasonable limits a corresponding similarity in uniformity of composition down the dip, for experience has shown that as a rule individual limestone or shale beds will remain uniform in chemical composition within the boundaries of the ordinary cement property. The lack of uniformity in a quarry is found oftenest in the chemical and physical differences of different strata rather than along the strike of a single bed.

Very satisfactory samples can be taken by means of the churn drill. This does not allow small seams and irregularities in the rock to be detected as well as does the core drill. On the other hand, it gives a better average sample of the rock than does the core drill, unless the core is broken up. Sampling with the churn drill can be done for about one-half the cost of the core drill. Where the churn drill is used, the mud which is taken from the drill hole is placed in a tub at intervals, say every 5 feet. The mud in this tub is thoroughly stirred and an average sample of several pounds is taken. This is dried and sent to the chemical laboratory for analysis.

With the churn drill great care must be taken that no surface clay is washed into the hole and also, when clay seams in the rock are drilled through, that material from them is not washed into the drillings.

What has been said about sampling limestones applies equally well to sampling shales and other argillaceous material. In taking samples, however, either of limestones or shales it should be borne in mind that the only samples that are representative or of any value are those which represent the fresh and unweathered rock. With the harder limestones fresh samples may be had very close to the surface, but as the limestones become more argillaceous and softer they are more easily attacked by the agencies of erosion, and the weathered surface has to be removed in order to obtain samples that can be regarded as correctly representative.

*Location with Respect to Fuel Supply.**

In addition to the suitable location of the raw materials with respect to transportation facilities and markets, amount of material, and the chemical composition, the physical character of the materials have to be considered as well as the location of the plant with regard to fuel supplies. With the invention and introduction of improved machinery for grinding, the matter of the physical character of the materials is not so important as it was some years ago. Nevertheless, in Portland cement manufacture, it is obvious that the softer and dryer the material the better, for then it can be more easily excavated and more easily ground and prepared for mixing.

The distance, however, of a Portland cement plant from its fuel supply and the freight rates obtainable from the railroads are seen to be extremely important when it is remembered that every barrel (380 pounds) of Portland cement represents a total consumption in kilns and plant of from 150 to 200 pounds of coal for the dry process or 200 to 250 pounds for the wet, or for a 3000-barrel plant an annual consumption of from 75,000 to 100,000 tons. The fuel consumption is thus seen to represent one of the largest items in cost of manufacture. In most places the average is about 30 per cent. of the total cost of production.

The composition of the coals used in the kilns for burning the Portland cement mixture to incipient fusion should fall within the following limits:

	Per cent.
Volatile matter	30-40
Fixed carbon	50-60
Sulphur	0-3
Ash	5-25

In other words, they should be bituminous coals high in volatile matter and correspondingly low in fixed carbon. The high-carbon coals, such as anthracite and semi-bituminous coal, give higher temperatures than the bituminous coals, but combustion takes place less rapidly when they are pulverized and blown into the kiln, and accordingly they give less

* The Coals of Maryland. Md. Geol. Survey, Vol. V, pp. 219-636.

satisfactory results. A bituminous coal closely corresponding in composition to the so-called "gas coals" is therefore to be preferred. The amount of sulphur should not exceed 3 per cent., and the nearer it approaches nothing the better. The content of ash should be low, principally because a high content of ash decreases the heating value of the coal, but also because about half of the ash goes into the mixture, and in large amounts this would contaminate and interfere to some extent with the composition of the finished product.

The coals of Maryland occur in the western part of the State in several distinct basins. The principal and most important of these basins is the Georges Creek, in which the well-known Pittsburg Seam is extensively mined. This synclinal area and the less important basins and coal beds of the State are discussed at length in Part IV, Volume V, of the Maryland Geological Survey reports, and for detailed information the reader is referred to that publication.

The Maryland coals on the whole, and particularly the coal mined from the Pittsburg Seam, are of excellent quality; but because of their high fuel ratio (3 to 4) are better suited for steam, domestic and smithing purposes than they are as gas-making coals and as kiln coals in the Portland cement industry.

Portland cement plants in Maryland will probably obtain their steam coals in Maryland and their kiln coals from West Virginia, where the analyses of the Pittsburg and other seams show a higher content of volatile matter and a lower amount of fixed carbon than the same coal seams in Maryland. The average of a large number of analyses of the Pittsburg Seam in Maryland and of the Pittsburg Seam in West Virginia are quoted below. These two average analyses show that the coal from the Pittsburg Seam in Maryland is lower in volatile hydrocarbons and higher in fixed carbon than the coal mined from the same seam in West Virginia. None of the Maryland coals would be considered typical gas coals since a content of as much as 25 per cent. volatile matter is considered a rare occurrence.

The following average analysis of the West Virginia Pittsburg Seam shows a rather high content of sulphur. Coals as low in sulphur as 1 per

cent., however, are to be had, and hence there would be no difficulty in obtaining kiln coal of suitable composition, and at cost at the plant little if any higher than if the coal were mined in Maryland.

AVERAGE ANALYSES OF PITTSBURG COALS FROM MARYLAND AND WEST VIRGINIA.

	Md.*	W. Va.†
Fixed carbon	72.96	53.83
Volatile matter	18.81	37.47
Moisture	.70	1.43
Ash	7.26	7.27
Sulphur	1.01	2.59

* Vol. V, Part IV, p. 633. Md. Geol. Survey.

† Vol. II, p. 205. W. Va. Geol. Survey.

MANUFACTURE OF PORTLAND CEMENT.

The Proportioning of Cement Mixtures.

Newberry, some 10 years ago, proposed a formula for calculating the relative proportions of clay and limestone which should be used in making cement. His formula is based on the assumption that the lime in cement is all combined to form dicalcium aluminate and tricalcium silicate. It was at one time extensively used in proportioning marl and clay and limestone and clay, and in spite of the fact that the assumptions upon which it was based have been recently shown to be wrong it is still used by many chemists for this purpose.

In the formula which Newberry proposed for the constitution of Portland cement, viz., $3\text{CaO} \cdot \text{SiO}_2 + 2\text{CaO} \cdot \text{Al}_2\text{O}_3$, one part of silica corresponds by weight to five parts of calcium carbonate, and one part of alumina to two parts of calcium carbonate. In the calculation the percentage of iron oxide is added to the percentage of alumina, the total being considered as alumina.

EXAMPLE 1. ANALYSES OF RAW MATERIALS.*

	Limestone.	Shale.
Silica (SiO_2)	7.06	62.20
Alumina (Al_2O_3)	1.08	21.25
Iron oxide (Fe_2O_3)	1.01	5.23
Calcium carbonate (CaCO_3).....	87.75	.64
Magnesium carbonate (MgCO_3)..	1.70	.94

* Partial analyses of raw materials used by the Security Cement and Lime Company, Security, Md.

The shale requires, according to the formulas:

Parts of Shale.		Ratio of CaCO ₃ .		CaCO ₃ required.
Silica (SiO ₂)	62.20	×	5	= 311.00
Alumina (Al ₂ O ₃)	21.25	×	2	= 42.50
Iron oxide (Fe ₂ O ₃)	5.23	×	2	= 10.46
				363.96
Calcium carbonate (CaCO ₃)	0.64			.64
				363.32

Since the limestone itself contains silica, alumina, and iron, part of its lime will be required to satisfy these constituents:

Parts of Limestone.				
Silica (SiO ₂)	7.06	×	5	= 35.30
Alumina (Al ₂ O ₃)	1.08	×	2	= 2.16
Iron oxide (Fe ₂ O ₃)	1.01	×	2	= 2.02
				39.48

This subtracted from the total CaCO₃ leaves 48.27 parts of CaCO₃ in each unit of limestone. As 363.32 parts of CaCO₃ are required for each unit of shale the units of limestone required per unit of shale will be:

$$\frac{363.32}{48.27} = 7.53$$

In other words, for each ton of shale are required 7.53 tons of limestone.

In actual practice the above calculation is simplified and accelerated by the use of diagrams and tables analogous to those employed in the operation of blast furnaces.

In practice, the full amount of lime called for by Newberry's formula is never employed, the percentage in all cases depending upon the fineness to which the raw materials are ground and the degree of burning. Usually about 90 per cent. of the lime called for by the formula is employed, or the figures 4.5 are used in place of 5 as the factor for the silica, and 1.8 instead of 2 as the factor for the alumina.

Practically all American Portland cements satisfy the formula (Michaelis' "hydraulic modulus"):

$$\frac{\text{per cent. Lime}}{\text{per cent. Silica} + \text{per cent. Iron Oxide} + \text{per cent. Alumina}} = 1.9 \text{ to } 2.1$$

Meade states * that in his work he found that where the raw materials were ground to a fineness of 95 per cent. through a No. 100 test sieve, he never failed to make a sound cement of normal setting qualities and good strength when the composition of this cement met the ratio:

$$\frac{\text{per cent. Lime}}{\text{per cent. Silica} + \text{per cent. Iron Oxide} + \text{per cent. Alumina}} = 2.05,$$

provided the ratio between the silica and the alumina was not less than 2.5.

In mill practice, however, it is seldom that as high a ratio as this can be carried. Just what the ratio should be depends upon conditions of manufacture and the nature of the materials. When the alumina is low this ratio is often carried as low as 1.9 without obtaining quick-setting cement. On the other hand, when the alumina is high it is often, but not always, necessary to carry the ratio as high as 2.05 to avoid quick-setting cement.

The formula used to proportion the raw materials so as to give a cement having a ratio of 2.05 is as follows:

Limestone (or Marl)

Clay (or Shale)

$$= \frac{(\% \text{ SiO}_2 + \% \text{ Fe}_2\text{O}_3 + \% \text{ Al}_2\text{O}_3 \text{ in Clay}) \times 2\frac{1}{4} - (\% \text{ CaO in clay})}{(\% \text{ CaO in limestone}) - (\% \text{ SiO}_2 + \% \text{ Fe}_2\text{O}_3 + \% \text{ Al}_2\text{O}_3 \text{ in limestone})} \times 2\frac{1}{4}.$$

The additional 0.2 added in the formula is to take care of the small amount of coal ash which enters the cement.

In the example given above the proportions of shale and limestone would be as follows:

$$\frac{\text{Limestone}}{\text{Shale}} = \frac{(62.20 + 21.25 + 5.23) \times 2\frac{1}{4} - 0.36}{49.14 - (7.06 + 1.08 + 1.01) \times 2\frac{1}{4}} = \frac{199.17}{28.58} = 6.98.$$

The formulas used above are very valuable in determining the relative parts by weight of limestone and shale entering into a Portland cement mixture, but after a plant has been put into operation and is running on materials of fairly uniform composition it is customary to "control the mix" according to a fixed lime standard, that is to say if it were found that 41.5 per cent. lime (CaO) in the mixture of raw materials

* Meade, R. K. 7th Int. Congr. of App. Chem.; see Chem. Eng., Vol. X, p. 181.

gave the best results the mixture would be made on this basis. In order to do this, however, the ratio of silica to alumina must, and would in a suitable shale deposit, remain approximately constant.

After it has once been determined what amounts of limestone and shale mixed together give the best results the mixture of raw materials may be calculated and controlled according to the percentage of lime (CaO) in the mixture by the following simple algebraical method: *

Where x = weight of limestone in charge.

y = weight of clay or shale in charge.

a = per cent. of calcium oxide in limestone.

b = per cent. of calcium oxide in the clay.

c = per cent. of calcium oxide in the mixture.

$$\text{Then } c = \frac{ax - by}{x - y} \text{ or } x(a - c) = y(a - b) \text{ or } \frac{x}{y} = \frac{c - b}{a - c}.$$

The problem of determining the probable composition of a cement from its raw materials is often presented. Its solution is by no means easy. The usual rule is to add together the percentages of silica, oxide of iron and alumina, lime and magnesia, and to divide this sum into the percentage of each compound, multiplied by 100, for the percentage of that compound which will be present in the clinker. If this rule is followed, the results obtained for silica and for iron oxide and alumina will be too low and the lime much too high. This is because the ash of the fuel enters into the composition of the clinker, and also because the clinker contains other constituents present in the raw materials and not entirely volatilized in burning, viz., soda, potash, sulphur trioxide, etc., carbon dioxide and water.

The accurate calculation of the composition of the clinker from an analysis of the raw material is, therefore, impossible, and the best that can be done is to assume certain corrections.† First of these is for the coal ash entering into the clinker. Experiments show that in the rotary kiln about one-half the ash enters the clinker. The West Virginia

* Ohio Geol. Survey, Bull. III, p. 242.

† Meade, R. K. 7th Int. Congr. App. Chem.; see Chem. Eng., Vol. X, p. 181.

gas-slack coal contains about 10 per cent. of ash in practice. This ash is composed of about 40 per cent. silica and about 20 per cent. each of iron oxide and alumina. If, therefore, 90 pounds of coal are required to burn a barrel of cement, about 16 pounds (equivalent to 1.5 pounds of ash) are required per 100 pounds of raw material burned. Assuming half the ash to enter the raw material, the silica in the latter is increased by $\frac{1}{2} \times 1.5 \times 0.40 = 0.30$ per cent., and the iron and alumina each by $\frac{1}{2} \times 1.5 \times 0.20 = 0.15$ per cent.

Analyses of Lehigh Valley clinker when fresh from the kilns show it to contain about 2 per cent. of potash, soda, sulphur compounds, carbon dioxide, and water combined. Clinker from other localities will probably not vary widely from this.

Assuming the above corrections, Meade's rule for calculating clinker from the mix analysis is as follows:

Add together the percentages of silica, alumina, oxide of iron, lime, and magnesia. To the sum add 2.75. Call the result the "Clinker Total."

To find the percentage of silica, add 0.30 to the percentage of silica in the raw material, multiply the sum by 100 and divide by the "Clinker Total" as found above. The result will be the percentage of silica in the clinker.

To find percentage of iron oxide, add 0.15 to percentage of alumina in the mix; multiply by 100 and divide by "Clinker Total," etc.

To find percentage of lime or magnesia, divide percentages of these by "Clinker Total," etc.

EXAMPLE. ANALYSIS OF RAW MATERIAL.

Silica (SiO_2)	13.44	
Alumina (Al_2O_3)	} 6.54	
Iron oxide (Fe_2O_3)		
Lime (CaO)	41.84	
Magnesia (MgO)	1.93	
	—	63.75
Correction for ash, etc.....		2.75
		—
Clinker Total		66.50

Percentage of Silica:

$$100 \times \frac{13.44 + 0.30}{66.50} = 20.66$$

Percentage of Alumina and Iron Oxide:

$$100 \times \frac{6.54 + 0.30}{66.50} = 10.29$$

Percentage of Lime:

$$100 \times \frac{41.84}{66.50} = 62.92$$

Percentage of Magnesia:

$$\frac{100 \times 1.93}{66.50} = 2.90$$

Probable composition of Clinker:

Silica (SiO_2)	20.66
Alumina (Al_2O_3)	} 10.29
Iron Oxide (Fe_2O_3)	
Lime (CaO)	62.92
Magnesia (MgO)	2.90

COST OF PORTLAND CEMENT PLANTS.

The capital required to build a cement plant depends on the cost of the kilns, the machinery installed, and the structures erected both for storage of the finished product and for the purpose of housing the machinery of the plant and the kilns. In short, it depends, as must be obvious, on the capacity and character of the plant.

The building of a cement works, aside from the original cost of the land that carries the necessary raw material, is an expensive undertaking and requires a large outlay of capital. The cost of plants ranges from a single 60-foot kiln plant, representing an expenditure of about \$150,000, to plants with five or more 125-foot kilns costing somewhat less per barrel produced, but requiring in the aggregate a capital of \$1,000,000 or more.

The authors know, however, of but one plant that has been built and put in operation recently where the cost was in the neighborhood of \$100,000. The plant referred to was a single-kiln plant built at Leeds, Alabama, by Major F. H. Lewis, and plans are now on foot to double its capacity. It is probable that a similar plant constructed under present conditions would cost nearer \$150,000.

In general it may be said that a Portland cement plant will cost from

\$1.00 to \$1.50 per barrel of its estimated output. That is, a plant producing 500,000 barrels per annum will cost from \$500,000 to \$750,000 as a construction charge. With economy of design and with the construction in experienced hands the first figure can be adhered to, but inexperienced engineers and constructors can readily run the cost beyond even the latter figure.

At present the tendency seems to be to start with a 2000- or 3000-barrel-per-day plant, costing from \$700,000 to \$1,000,000, with the plant so designed that later on other units may be added to the original battery. This arrangement for future expansion entails a larger first cost per barrel of output, but proves a final economy as the capacity of the plant is increased. It is probable that no plants of smaller capacity than 2000 barrels per day could now be operated at a profit in Maryland.

In the early days of cement making 60-foot kilns, 6 feet in diameter, were almost universally used. With the development of the industry has come the introduction of larger and longer kilns, so that now the length of kiln used is from 80 to 250 feet. The length, however, in most of the plants of recent construction ranges between 120 and 130 feet, and the diameter between $7\frac{1}{2}$ and 8 feet.

The relative capacity of kilns of different lengths and diameters is given in the following table:

DAILY CAPACITY OF KILNS OF DIFFERENT LENGTHS.

60 × 6 foot kiln is 200 barrels.
100 × 7 foot kiln is 400 barrels.
120 × 8 foot kiln is 500 barrels.
150 × 9 foot kiln is 750 barrels.

The fuel required to burn a barrel of cement decreases with the length of the kiln, and has been found in actual practice to be about as in the table that follows:

POUNDS OF COAL PER BARREL OF CEMENT (380 POUNDS) IN KILNS OF DIFFERENT SIZES.

60 × 6 foot kiln is 110 pounds.
80 × 6 foot kiln is 100 pounds.
100 × 7 foot kiln is 90 pounds.
150 × 9 foot kiln is 80 pounds.

Thus it may be seen that as the length of the kiln is increased not only is there an increase in the capacity, but also a marked decrease in the per barrel cost of fuel because of the heating of the mixture at the upper end of the kiln before it reaches the intenser temperatures below, all of which is in favor of larger sized kilns. Some of the best authorities on the subject believe the tendency to lengthen the kiln is being overdone, and that kilns of about 100 feet in length, all things considered, give the best results in ordinary work even though in certain cases it may be shown that the cost per barrel is less with the longer kiln. It is evident that on this point there is a wide difference of opinion.

The economy of a kiln is not only dependent on its length but also its diameter. Of two kilns, each 100 feet long, one of which is 6 feet in diameter and the other 7 feet, the former will be found to have the greater economy and the latter the larger output. The longer the kiln the more economical it would be, and on this score a kiln 200 feet long would not be too long, but with such a long kiln mechanical difficulties are met with which so far have more than overbalanced the economy effected. Kilns 250 feet long and 12 feet in diameter are now being installed at a plant on the Hudson River.

Instead of using a long kiln, the Fuller Engineering Company, designers of the plant of the Tidewater Portland Cement Company, at Union Bridge, are installing dryers after the kilns, through which the waste gases from the kilns are passed and utilized in drying the shale and limestone. This system obviates the necessity for kilns longer than 125 feet.

The total cost of manufacture of a barrel of Portland cement varies with the locality. Portland cement made by the dry process ranges in cost per barrel between 50 and 85 cents, while by the wet process, where marls are mixed with muds and clays, the cost is greater owing to the cost of drying the marl, and owing to its wet condition while excavating and transporting it to the mill. The selling price ranges between \$1.25 and \$1.50 a barrel, depending upon trade conditions, and thus the manufacturer situated near a large market even after paying for trans-

portation and selling costs is usually left a very flattering margin of profit, though not always, as for instance, when the cost of manufacture runs high because of unusual local conditions. This, unfortunately, sometimes happens as the result of insufficient care having been taken in the selection of the raw materials, the design of the plant, the location of plant, with reference to transportation, fuel supply, and market, and a neglect to arrange the question of rates with the transportation companies upon whom the plant is dependent for assembling the materials entering into the manufacture and for marketing of the finished product.

OTHER CEMENTS.

Before leaving the discussion of cements it seems advisable to add a brief discussion of several other cements not made from limestone, such as slag and oxychloride cements.

SLAG OR PUZZOLAN CEMENTS.

Slag or puzzolan cements are made from blast-furnace slag or natural puzzolan. The former should contain from 22 to 30 per cent. of silica; 11 to 16 per cent. alumina and iron oxide; 49 to 52 per cent. of lime; less than 4 per cent. magnesia; 1.5 per cent. alkalies, and show less than 2.5 to 7.5 per cent. loss by ignition. The puzzolan or volcanic tuffs usually run higher in silica, about the same in alumina, very much lower in lime, but with from 5 to 9 per cent. in alkalies which are practically lacking in slags.

Slag is locally abundant as the chief waste product of blast furnaces where its utilization would be appreciated. Since for cement purposes the slag must be of uniform composition, and since such uniformity cannot be maintained when different ores are used without endangering the uniformity of the pig iron produced, the blast-furnace operators who use more than one kind of ore prefer to leave the slag unutilized rather than lower the standard quality of their iron.

Slag cements are usually more porous and less resistant to disintegration and abrasion than Portland cements, though generally serving well for marine work. From these and other cognate reasons little slag

cement is produced in America, the only plant making it in Maryland suspending operations several years ago.

OXYCHLORIDE CEMENTS.

Oxychloride cements are of less commercial importance than any of the other complex cements. They differ from the latter in that they are entirely free from silica, and their setting properties are due to the formation of hydroxychlorides.

The oxychloride cements are made by treating magnesia (MgO) with a solution of magnesium chloride ($MgCl_2$) of 25° to 30° Baumé. A paste is thus formed which sets tolerably rapidly and results in a hard, white mass that possesses unusual compressive strength and a tensile strength exceeding that of Portland cement. They are poor conductors of heat, easily molded and satisfactory for certain kinds of refined dental and interior work, but their permanence, compared with that of other cements, is still a matter of discussion.

SUMMARY AND STATISTICS OF LIME AND CEMENT INDUSTRIES.

The industries based upon the utilization of limestones are important and are constantly increasing in their gross production. These may be grouped according to the form in which the product reaches the market and the uses to which they are put by the consumer. *Limestone*, as such, is used rough or dressed for building purposes, paving, riprap, etc.; crushed for road-making, railroad ballast, and concrete; and in various forms for metallurgical and chemical purposes. The extent of the trade in limestone, exclusive of marble, may be seen from the following table indicating the value of the annual production in the United States:

VALUE OF THE ANNUAL PRODUCTION OF LIME AND LIMESTONE, EXCEPTING MARBLE, IN THE UNITED STATES.

	Building.	Flagging, curbing, paving.	Rubble, Riprap.	Crushed.	Flux.	Sugar.	Misc.	Lime burned.	Total
1900	\$4,380,706	.....	\$582,488	\$3,953,469	\$3,687,394	.....	\$529,900	\$6,797,496	\$20,181,
1901	5,219,310	\$463,925	1,024,109	5,271,642	4,569,896	.....	1,171,045	8,204,054	26,014,
1902	5,563,034	573,652	1,644,886	7,452,730	5,271,252	.....	492,384	9,335,618	29,993,
1903	4,981,241	1,037,888	1,214,540	8,580,866	5,423,732	.....	422,826	9,255,882	31,216,
1904	4,543,760	574,945	1,860,732	9,558,626	4,702,768	[\$613,649]	324,484	9,951,456	31,516,
1905	5,312,183	643,012	1,518,898	10,487,638	7,004,265	[408,548]	650,666	10,941,680	36,558,
1906	5,098,631	930,422	1,474,660	11,073,265	7,612,692	822,330	315,042	12,480,653	39,807,
1907	4,580,226	1,008,229	1,687,773	13,675,453	9,144,489	316,860	1,324,601	12,656,705	44,394,
1908	4,566,522	593,297	2,254,882	12,908,207	5,905,241	361,186	1,092,667	11,091,186	38,773,

The figures show a very stable industry in which the total annual production has increased slowly but steadily in sympathy with the general increase in population and wealth in the United States. The most noticeable features of the industry supplying stone for special uses are the steady and relatively rapid growth in the output of stone for flux and the crushed stone used in road, railroad, and concrete work.

The burning of limestone to lime is likewise an industry increasing rather steadily with the growth of the country. The uses to which the burnt lime is put are for building, agricultural, and chemical purposes. The accompanying table gives the value of the annual production in the United States since 1896:

VALUE OF THE ANNUAL PRODUCTION OF LIME IN THE UNITED STATES, 1896-1908.

1896	.....	\$6,327,900
1897	.....	6,390,487
1898	.....	6,886,549
1899	.....	6,983,067
1900	.....	6,797,496
1901	.....	8,204,054
1902	.....	9,335,618
1903	.....	9,255,882
1904	.....	9,951,456
1905	.....	10,941,680
1906	.....	12,480,653
1907	.....	12,640,512
1908	.....	11,091,186

The industries based upon the use of limestone in the manufacture of cements are of special importance and interest both because of the remarkable growth of the Portland cement industry and the accompanying decline in the production of natural cement.

The following table, based upon the estimates of early production by Cummings * and the recent statistics gathered by the U. S. Geological Survey, is a comparative statement of the production in the gross quantities produced annually:

* Cummings, American Cements, 1898, p. 298.

	Natural Blbs.	Portland Blbs.	Puzzolan Blbs.
1818-1830	300,000	.....	.....
1830-1840	1,000,000	.....	.....
1840-1850	4,250,000	.....	.....
1850-1860	11,000,000	.....	.....
1860-1870	16,420,000	.....	.....
1870-1880	22,000,000	82,000	.....
1880-1890	43,589,067	1,477,000	.....
1890	7,082,204	335,500	.....
1891	7,451,535	454,813	.....
1892	8,211,181	547,440	.....
1893	7,411,815	590,652	.....
1894	7,563,488	798,757	.....
1895	7,741,077	990,324	.....
1896	7,970,450	1,543,023	12,265
1897	8,311,688	2,677,775	48,329
1898	8,418,924	3,692,284	150,895
1899	9,868,179	5,652,266	335,000
1900	8,383,519	8,482,020	365,611
1901	7,084,823	12,711,225	272,689
1902	8,044,305	17,711,225	478,555
1903	7,030,271	22,342,973	525,896
1904	4,866,331	26,505,881	303,045
1905	4,473,049	35,246,812	382,447
1906	4,055,797	46,463,424	481,224
1907	2,887,750	48,785,390	557,252
1908	1,686,682	51,072,012	151,451
	227,102,085	395,567,395	4,145,657
			626,815,137

From the foregoing table it may be rapidly seen that of the three hydraulic cements Portland cement is easily chief. The figures also display the wonderful growth in this industry during the present generation. In 1880 the total output of Portland cement was only 42,000 barrels, less than one one-thousandth of the present annual production, and only 1.8 per cent. of the cement now consumed each year. At the same time natural cement was produced to the extent of 2,030,000 barrels. In the meantime the production has increased to a maximum annual production of 9,868,179 barrels in 1899, only to decline during the last decade to a production below that of 1880.

Puzzolan or slag cement has never been produced extensively in this country, the annual production scarcely exceeding 1 per cent. of the Portland cement manufactured during corresponding years.

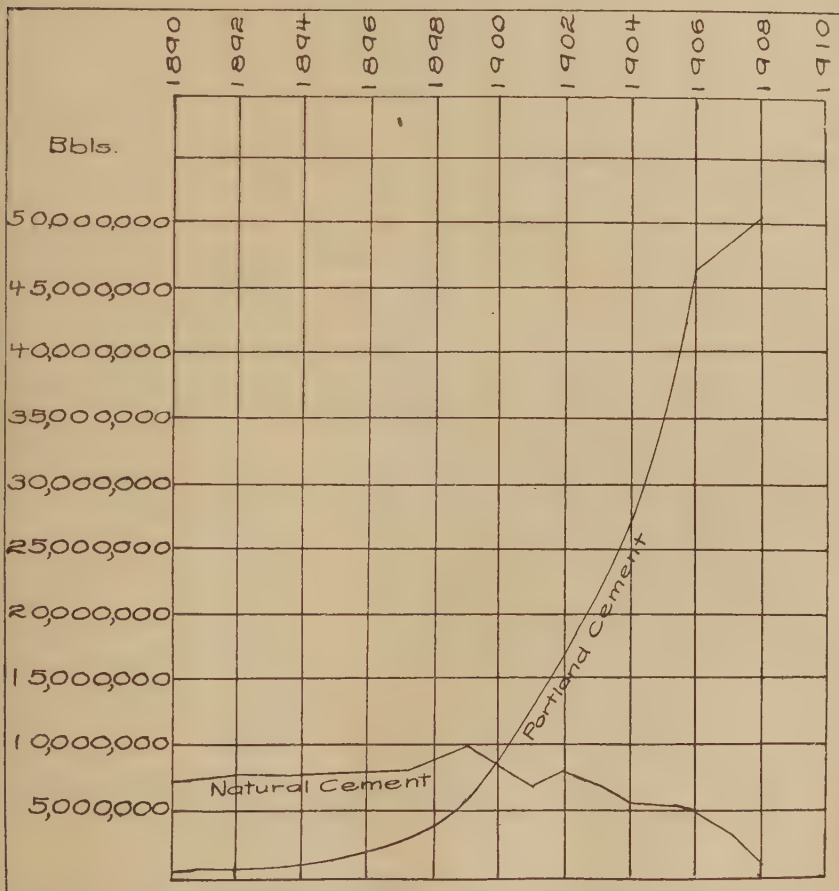


FIG. 19.—Diagram showing production of Natural and Portland Cements, 1890-1908.

The annual production of each variety for the year 1908, with its value and price per barrel, is as follows:

	Quantity.	Value.	Price per bbl.	Rela. price.
Portland	51,072,612	\$43,547,679	\$.85	\$1.00
Natural	1,686,682	834,509	.44	.73
Puzzolan	151,451	95,468	.63	.74
	52,910,925	\$44,477,653		

The price per barrel is the average price f. o. b. at the mill. Since natural cement barrels contain only 265 pounds as against 380 pounds in barrels of puzzolan and Portland cements, their relative prices per pound are more favorable to natural cement than appears. Puzzolan and natural cements cost between 70 and 75 per cent. of Portland, weight for weight.

The phenomenal growth of the Portland cement industry is shown in the following figures, which show the annual production of natural, Portland, and puzzolan cements and pig iron.

PRODUCTION IN SHORT TONS OF CEMENT AND PIG IRON.

	Natural.	Portland.	Puzzolan.	Pig Iron.
1890	938,392	67,100	.....	10,307,073
1891	987,328	91,000	.....	9,269,454
1892	1,087,976	101,500	.....	10,255,840
1893	982,065	114,100	.....	7,979,442
1894	1,002,162	159,700	.....	7,456,274
1895	1,025,693	199,700	.....	10,579,864
1896	1,056,085	308,600	2,530	9,657,902
1897	1,101,299	535,500	9,183	10,811,001
1898	1,115,494	716,900	28,670	13,186,806
1899	1,307,584	1,161,100	63,650	15,255,187
1900	1,110,816	1,696,400	69,466	15,443,951
1901	938,639	2,542,200	51,811	17,783,756
1902	1,065,880	3,446,100	90,925	19,959,863
1903	931,511	4,458,600	99,920	20,170,362
1904	640,764	5,601,200	57,579	18,476,676
1905	592,679	6,665,304	72,665	25,751,465
1906	537,394	8,828,050	78,132	28,344,053
1907	362,545	9,269,224	105,928	28,875,124
1908	223,485	9,703,896	28,776	17,848,340

LIME AND CEMENT MATERIALS IN MARYLAND.

INTRODUCTORY.

THE GEOGRAPHY OF THE STATE.

The State of Maryland is divided into three physiographic provinces, known as the Coastal Plain, the Piedmont Plateau, and the Appalachian Region. The Piedmont Plateau lies between the Appalachian Region on the west and the Coastal Plain on the east. The Appalachian Region

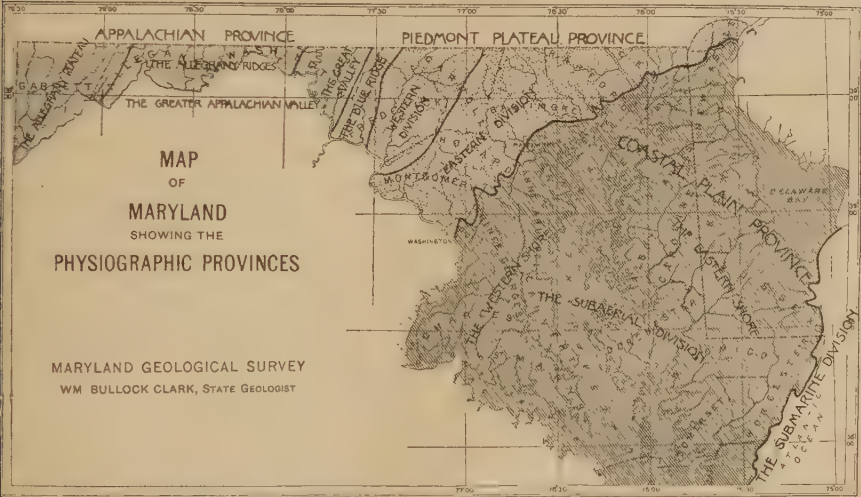


FIG. 20.—Map of Maryland showing the Physiographic Provinces.

includes all that part of the State west of North Mountain, and is subdivided into the region of the Alleghany Ridges and into a more western region, the Alleghany Plateau. The Coastal Plain lies east of the sinuous line shown on the accompanying map. This line passes across the State in a northeasterly direction through Washington and Baltimore and the mouth of the Susquehanna. The Coastal Plain is divided into aerial and subaerial portions. The Piedmont is also divided. That part of the Plateau province east of the Blue Ridge, which is the Piedmont

proper, is separated into an eastern and western division by Parr's Ridge, while the area west of the Blue Ridge is referred to as the Great Valley Region.

THE GEOLOGY OF THE LIME AND CEMENT MATERIALS.

Each of the physiographic provinces briefly described above differs both in the matter of topography and geology. There is a gradual rise in elevation from the low-lying Coastal Plain of the east to the mountainous Appalachian Region of the west. Going from the eastern part of the State to its western boundary the traveler, besides reaching higher and higher altitudes, crosses first the younger deposits of the Coastal Plain, then the ancient rocks of the Piedmont, and finally traverses strata that, geologically speaking, become progressively younger.

The youngest formations of the State are confined to the Coastal Plain, where they consist of clays and other more or less poorly consolidated sediments. As a result of the absence of hard and resistant rocks in this section of the State it is low and flat, and but for its terraces is relatively featureless as regards topography. In this respect it is unlike the Piedmont Plateau, where the topography is rolling and undulating and the rocks are both harder and older and different in character from those of the adjoining Coastal Plain. The rocks of the western and mountainous part of the State are, on the other hand, younger in age than those of the Piedmont, but are much older than most of the rocks of the Coastal Plain. Moreover, considered as a whole, they are quite different in a great many respects from the characteristic rocks of the two provinces first referred to above.

Argillaceous and calcareous materials occur in all three of the regions that have been discussed. In the eastern Piedmont the limestones are best developed in the vicinity of Texas and Cockeysville, while suitable argillaceous material occurs near at hand in the Coastal Plain. The Mesozoic and Cenozoic rocks of the latter physiographic division also carry marls which, as the result of exploitation work, may prove to be a source of cement material. Furthermore, the regions of the Piedmont and Coastal Plain are traversed by numerous railroads. These, together

with convenient and cheap water transportation, afford a means of assembling the raw materials and likewise the facilities for carrying the finished products to local and distant markets.

Suitable materials for making lime and cement occur in the western Piedmont section, but not so abundantly as farther west. Some of the limestones of this section which occur along the line of the Western Maryland Railroad, especially those deposits near Union Bridge, are extremely pure and are found in sufficient quantity to form the basis of a small but thriving industry. They are about to be used in conjunction with the associated volcanic slates and the nearby Triassic shales to form the basis for the manufacture of Portland cement. A plant located in this region would have to depend entirely on the one railroad, the Western Maryland, now known also as the Wabash, for transportation. It would have the advantage, however, of being within 50 miles of Baltimore and near Washington, also, both large markets for Portland cement.

Limestone of known Cambro-Ordovician age occurs on both sides of the Blue Ridge. East of the Blue Ridge this limestone is of great thickness and of wide distribution, and contains beds of varying degrees of purity; it occurs in the vicinity of Frederick and forms what is known as the Frederick Valley. From Frederick northward it is traversed by the Northern Central Railway of the Pennsylvania system, and southwest and eastward by the Baltimore and Ohio Railroad. Both lines center at Frederick and furnish transportation facilities for assembling (depending on which is desired) either the shales of volcanic and undetermined origin on the east side of the valley, or the Triassic shales on the west at some fixed point for manufacture within the limestone belt, and along one or the other of the routes mentioned.

The largest areal distribution of limestone in the State is in the Hagerstown Valley. Shale also occurs in abundant quantity and deposits of suitable quality for the manufacture of Portland cement may usually be found without very great difficulty. The valley is traversed by five different railroad lines that center and radiate from Hagerstown. By reason of the transportation facilities and the abundance of raw materials this valley region is probably the most promising field for the investiga-

tion and successful location of cement materials in Maryland. The only Portland cement plant now in operation in the State is located within this section, near Hagerstown, and unless this plant is followed in the near future by the building of one or two others it will be most surprising.

The limestones of the mountainous section of Maryland are neither so thick nor so accessible for working as the beds of the Shenandoah group of limestones that form the floor of the Hagerstown and Frederick valleys. These mountain limestones, namely, the Cayuga, Helderberg, and Greenbrier, are much higher up in the geological column than the limestone beds of the Hagerstown Valley. The Western Maryland or Wabash Railroad cuts across the strike of these mountain limestones at a number of points in the western part of Washington County and between Hancock and Cumberland. Several railroads center at Cumberland, and a number of very promising points for the location of plants for the manufacture either of lime or cement are known to occur. These are discussed in detail on a later page.

USES, VALUE, AND DISTRIBUTION BY DISTRICTS.

The limestones of Maryland which are largely used in structural work and for building purposes, and as the basis of both its lime and natural cement industries, and are likewise equally necessary in the manufacture of Portland cement, occur in workable quantities in 7 of the 23 counties of the State, and if Harford is included outcrop in 8.

The limestones of Harford, Baltimore, Howard, and Carroll, and those also of Frederick, with the exception of the group of Shenandoah limestones, occupying the Frederick and Glade valleys, will be discussed under the head of Piedmont limestones. The Shenandoah limestone of Frederick will be discussed later under the head of Frederick Valley limestones, and the limestones of the same age occurring in Washington County under the caption Hagerstown Valley. Finally, the limestones of the western part of Washington County which were laid down at a later geological time than the Shenandoah will be considered along with

the limestones of Allegany and Garrett counties, in reference to their chief occurrence in the Appalachian division.

PIEDMONT PLATEAU.

Piedmont Plateau is the name used for the physiographic division of the State that extends from the Coastal Plain on the east to the Catocin or Blue Ridge mountains on the west. Excepting the Triassic area and the Shenandoah limestones east of the Blue Ridge the characteristic rocks of the region are extrusive and intrusive igneous rocks, both altered and unaltered, together with more or less metamorphosed representatives of limestones, shales, and sandstones. These rocks give this region its characteristic undulating, and in certain sections noticeably hilly, topography. The hard quartzites and rocks of igneous origin, but chiefly the former, are the main ridge-makers and form the ridges on one side of the valleys occupied by limestones, while hills or ridges composed of schists may rise to lower altitudes on the other.

For the convenience of discussion the Piedmont section is divided into an eastern and a western section. Within the former occur the limestones and schists and quartzites of Harford, Baltimore, and Howard counties. The limestones and marbles of this region lie to the east of the northeast-southwest boundary line separating the counties of Baltimore and Carroll. Between this boundary and a line on the west passing through Frederick Junction, having the direction $N\ 30^{\circ}-35^{\circ}\ E$, are found the crystalline limestones, shales, slates, schists, quartzites and altered volcanic of the western division of the Piedmont. The limestones of this western division are confined to two counties, Carroll and Frederick.

The accompanying map, Figure 20, showing the physiographic provinces of the State takes Parris Ridge as the dividing line between the eastern and western Piedmont divisions. This is the most natural line of division between the two sections, for Parris Ridge extends in a northeasterly direction from the Potomac entirely across the State into Pennsylvania. It is the most prominent topographic feature of the central Piedmont, and acts as a watershed which separates the Piedmont

into two distinct drainage areas. However, as certain of the limestones characteristic of the western division of the Piedmont are exposed northeast of Westminster, it has been thought best to take for the present discussion a dividing line which follows in its northeastern part the boundary between Baltimore and Carroll counties.

EASTERN DIVISION OF THE PIEDMONT.

The limestones of the eastern division of the Piedmont are well developed in Baltimore County, but occur sparingly and are of little economic importance in both Harford and Howard. They apparently underlie the Wissahickon schists and are superjacent to the Setters quartzites. Their exposure in and occupancy of the larger and more fertile valleys, particularly the valleys of Baltimore County, is the result of structural relationships, and is due also to the fact that limestones are unable to withstand, like schists and quartzites, the erosive agents of nature.

Geology.

GEOLOGICAL STRUCTURE.—The structure and trend of the rocks of this section are strikingly similar to the structure and trend as exhibited in the Appalachians.* Their minor folding, showing synclines succeeding anticlines and small overturns and faults, has, in a measure, furnished the key that has led to the present understanding and interpretation of the major structure of the region. This, however, involving as it does an earlier deformation, probably Taconic in age, is far more complicated and has been worked out with much more difficulty than the much simpler and more apparent stratigraphic relationships seen within the region of the Appalachians. The forces that were exerted at the close of the Paleozoic resulted in the complicated folding of the rocks of the eastern and western Piedmont and in the more open folding of the Appalachians. This is seen in the parallel trend of their rocks and the concentric arrangement of the formations of the three regions about a common center situated near Baltimore.

* Mathews, E. B. Geol. Soc. Amer. Bull., Vol. 16, p. 342.



FIG. 1.—BEAVER DAM QUARRY, COCKEYSVILLE.



FIG. 2.—WEST END OF DITMAN QUARRY, TEXAS.

VIEWS OF EASTERN PIEDMONT QUARRIES.

The limestones and associated metamorphosed sedimentary rocks of the eastern Piedmont have a general northeasterly strike and trend, which bends around still further to the east as the rocks are followed from the southern exposures in Harford through Baltimore and Howard counties. Situated near the center of the radiating movements whose action in a southeasterly to northwesterly direction brought about the deformation, elevation, and deflection eastward of the Appalachian strata, the rocks of the eastern Piedmont have in consequence been subjected to forces of the most complex nature.

The formations of this region are folded into synclines and anticlines, here and there partially overturned, and in places faulted and cut by igneous intrusions; but the most unusual feature is the torsional folds which have recently been described by the senior author.*

GEOLOGICAL AGE.—The limestone of Baltimore County has been correlated with the Shenandoah limestone and its age is therefore thought to be Cambro-Ordovician. Fossil forms by which its age might be more accurately determined have never been found. They are probably entirely absent, having been destroyed by strong metamorphic action. The heat and pressure concomitant with the metamorphism to which this limestone has been subjected not only has removed, so far as known, all trace of fossil remains, but has also completely changed the original character of the rocks. Once a limestone composed for the most part of amorphous calcium carbonate, it is now a highly crystalline marble largely composed of grains of calcite and dolomite. Physically, it varies in texture from being loose granular to fine-grained, compact, and highly cemented crystalline limestone or marble. At the typical occurrence at Cockeysville, in Baltimore County, it occurs in the latter form, and has hence been given the name Cockeysville marble.

This crystalline limestone or Cockeysville marble has, as mentioned above, been correlated with the Shenandoah limestone. Nevertheless for the reasons that have been stated its exact position in the stratigraphic column has never been definitely determined. The fact, how-

* Johns Hopkins Univ. Cir., 1907.

ever, that on either end of the extension of the Cockeysville marble and the underlying and superjacent formations there is a sequence into sedimentary rocks of known horizon affords a correlation such as given, but one which, no matter how striking and convincing it may be, until further data are adduced, can be only tentative and unsatisfactory.

However, for use in economic work the age of this crystalline limestone is not nearly as important as its actual occurrence, its quality, thickness, and its availability for use in making limes and cements. It varies in thickness from 0 feet to 2300 feet, and has an average thickness that has been estimated to be a little over 1100 feet. The quality of the stone is another variable quantity. It ranges from an almost pure coarse-grained calcium carbonate to one high in magnesium carbonate and finer in grain. It may also contain at the same time different amounts of other impurities. It is worked principally in the vicinity of Texas and Cockeysville. It has also been quarried for building purposes or to burn into lime elsewhere in Baltimore County, but compared with the operations of the Texas-Cockeysville district these have been unimportant and comparatively insignificant.

Distribution of Lime and Cement Materials in the Eastern Piedmont.

CALCAREOUS MATERIALS.—The establishment of a Portland cement industry in the eastern Piedmont requires satisfactory argillaceous and calcareous raw materials. The lime-burning industry, however, requires only the latter. The available argillaceous materials consist of residual clays and schists and clays of the Mesozoic and Cenozoic formations which occur nearby within the region of the Coastal Plain. The calcareous materials are limited to the Piedmont.

The most valuable deposits for lime and cement in the eastern Piedmont are found on either side of the main line of the Northern Central Railroad between Sherwood and Cockeysville, and along the Maryland and Pennsylvania Railroad between Lock Raven and Glen Arm. The most extensive operation at present is in the northern portion of the former area in the vicinity of Texas and Cockeysville.

Cockeysville and Texas District.—At Texas the stone is quarried chiefly to burn into lime and to a smaller extent for use for fluxing and building purposes. On the other hand, the more compact, close-grained stone around Cockeysville is taken out chiefly for building purposes. Some of it, however, is also channeled especially for monumental and statuary work, while a small tonnage of the product goes to the neighboring kilns and is there burned into lime.

The limestones of Baltimore County are represented by five distinct types of stone known to the quarrymen by the following names:

1. Alum stone.
2. Blue stone.
3. Dolomite.
4. Magnesian stone.
5. Mica-banded limestone.

Each has its characteristic mineralogical and chemical content and distinctive physical appearance; and, moreover, each differs more or less in the uses to which it is best adapted and the purposes for which it is generally employed.

The *alum stone* is a coarsely crystalline limestone which occurs typically exposed in the Ditman quarry west of Texas. It is composed of large and small grains of calcite averaging about $\frac{1}{8}$ of an inch in diameter. These are rather poorly cemented together. It is thus a very loose-textured crystalline limestone, and hence a sample the size of ordinary hand specimens may be shattered easily and separated into individual grains by one or two sharp blows from a hammer. The color is pure white and the stone is called "alum stone" in reference to its supposed resemblance after calcination to large lumps of alum. In composition it is usually extremely pure, as may be seen from the analyses (Nos. 10-11) below. It is less contaminated by impurities, and the presence of accessory minerals than any of the other varieties of limestone occurring in the eastern Piedmont. The accessory minerals most noticeable megascopically are occasional small crystals of pyrites and chalcopyrite. Because of its high content of calcium oxide and loose-textured character

the alum stone is more suitable for manufacture into lime than it is as a building stone or as a road metal, and is accordingly extensively used for the former purpose. In view of its low content of silica and alumina it has also proved acceptable as a fluxing stone either for the open-hearth or blast furnace, and because of its low content of magnesia would be equally well adapted to the manufacture of Portland cement.

ANALYSES OF COCKEYSVILLE LIMESTONE, DITMAN QUARRY, TEXAS.

	No. 10.	No. 11.	No. 13.
Silica (SiO_2)	.36	2.10	4.90
Alumina (Al_2O_3)	.20	.61	1.11
Lime (CaO)	52.72	53.70	50.92
Magnesia (MgO)	.19	.61	1.34
Carbon dioxide (CO_2)	43.77	42.54	41.03
Total	100.24	99.56	99.30

No. 10. Typical specimen of alum stone, Ditman Quarry.

No. 11. Represents 50-foot face of alum stone, Ditman Quarry.

No. 13. Typical specimen of "blue stone," north side Ditman Quarry.

The sample on which the second analysis (No. 11), the bulk sample, was made was taken near the center of Ditman's Quarry and in a direction S. 75° W. from the main battery of kilns, and represents 50 feet of stone or the entire face at this point of the quarry. The alum stone is here flanked on either side by two different types of stone. On the north the so-called "blue stone" is quarried, and on the south the magnesian variety. All three varieties are burned for lime and each yields a different grade, the best lime being produced from the alum stone. The "blue stone" produces a high-calcium lime, while the magnesian stone yields a lime high in magnesia.

All three varieties of stone exposed in the Ditman Quarry have a general westward dip of 15° to 18°. The limestone is fissured throughout the exposure, and especially at the north end of the quarry. Here the fissures dip steeply to the east, the exact angle being close to 85°, and strike N. 70° W.

The "*blue stone*" is a hard, compact crystalline limestone of a prevailing grayish-blue color. Bands of varying width of grayish-blue color

alternate with bands which range in color through light gray to dove and almost white. Like the alum stone it is composed of grains of calcite whose glistening faces make the crystalline character of the rock evident at a glance. These are tightly cemented together so that the rock may be used either as a building stone or burnt into lime. It contains more silica, alumina, and iron than the "alum stone," but nevertheless burns into an excellent grade of lime. It is also low enough in magnesia for manufacture into Portland cement.

The quantity of blue and alum stone in the quarry appears to be ample to furnish the necessary calcareous material for a Portland cement plant of 1500 to 2000 barrels daily capacity for period of at least 25 years, but in order to determine this definitely further and more detailed investigation would be necessary. Analysis No. 13 gives the composition of the blue stone.

The *dolomites* and dolomitic limestones, when the impurities of silica, alumina, and iron are low or are practically absent, are white and hard, and are further characterized by their close-grained texture. They may be seen typically exposed in the marble quarries at Cockeysville where the samples represented by the following analyses were collected:

ANALYSES OF DOLOMITE, BEAVER DAM QUARRY, COCKEYSVILLE.*

	No. 3.	No. 4.
Silica (SiO_2)	0.44	5.57
Alumina (Al_2O_3)	1.22	.40
Iron oxide (Fe_2O_3)	Trace	
Lime (CaO)	30.73	29.08
Magnesia (MgO)	20.87	20.30
Ignition (CO_2 , etc.)	47.07	44.26
Total	100.33	99.61

* U. S. Geol. Survey, Bull. No. 150, p. 801.

It may be observed from the above analyses that the argillaceous substances are low while the content of magnesia is high. Burning such a stone would yield a lime too high in magnesia for the average commercial use. The stone is well adapted for building purposes, however,

and is extensively quarried by the chief operator at Cockeysville, the Beaver Dam Marble Company, the product going almost entirely to meet the demands of the building trade.

The extent to which accessory minerals, such as phlogopite, tremolite, biotite, and pyrite occur in the Cockeysville stone is the result not only of the metamorphism which has converted these limestones and dolomites into marble, but is due likewise to the presence in the stone of impurities like silica, alumina, iron, etc. The abundance and variety of accessory minerals depend obviously on the composition of the rock just as much as they do on the heat and pressure to which it has been subjected. The content of accessory minerals in which iron occurs as an essential constituent should be quite low in a marble or limestone that is to be used in exterior structural work. If this is not the case the stone becomes streaked on oxidation of the iron with stains that detract materially from its general appearance.

The above analyses of the Cockeysville marble indicate that the amount of accessory minerals that would be formed would be more or less insignificant because of the small percentage of the necessary elements. Those that do occur principally are tremolite, diopside, and minute and microscopic crystals of phlogopite. In the selected rocks, however, classified here as dolomites, with especial reference to the typical pure white Cockeysville marble, the impurity minerals mentioned form such a small fraction of a per cent. of the whole that they may be considered as occurring in purely negligible quantities in the stone placed on the market.

The term *magnesian stone* is applied to the variety of Cockeysville limestone containing phlogopite, biotite, and other accessory minerals formed from the argillaceous elements silica, alumina, and ferric oxide, as the result of metamorphism. These glistening flakes of yellow and black mica that are rather evenly distributed through the rock, give it a characteristic appearance by which it may always be easily identified.

The following analysis was made on a sample of this stone in which phlogopite was the dominant accessory mineral taken as representative

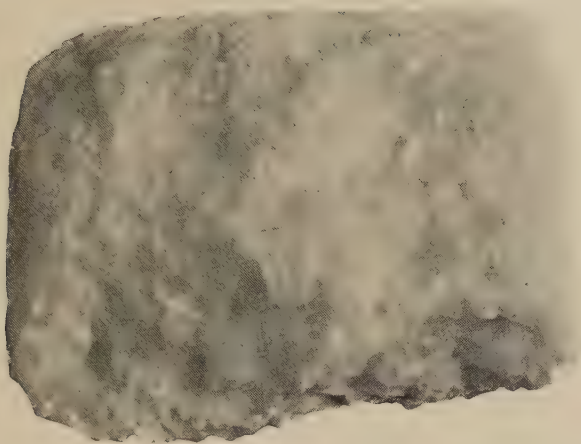


FIG. I.—“ALUM STONE,” DITMAN QUARRY, TEXAS.
WHITE CRYSTALLINE MARBLE COMPOSED OF LARGE CRYSTALS OF CALCITE.

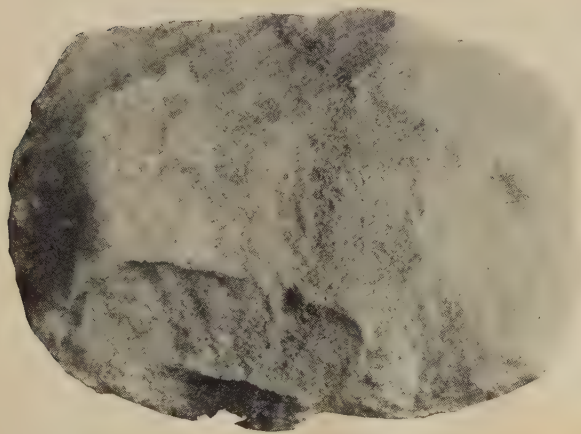


FIG. 2.—BANDED MAGNESIAN STONE, DITMAN QUARRY, TEXAS.
SHOWING WHITE CRYSTALLINE STONE CROSSED BY BAND IMPREGNATED WITH BROWN MICA.

TYPICAL LIMESTONES OF EASTERN PIEDMONT.

of the crystalline limestone quarried at the south end of Ditman Quarry at Texas:

ANALYSIS (No. 12) OF MAGNESIAN STONE, DITMAN QUARRY, TEXAS.

Silica (SiO_2)	6.65
Alumina (Al_2O_3)	} 2.08
Iron Oxide (Fe_2O_3)	
Lime (CaO)	33.58
Magnesia (MgO)	15.34
Ignition	41.32
	98.97

This stone when calcined necessarily yields a quick-setting high-magnesian lime. The value of the lime, however, is diminished by its content of mica. The heat of the kiln has very little effect on this mineral, and hence after calcination it is found in the lime in even greater amount than it was in the original rock.

This variety of limestone, known as *mica-banded rock*, has been so called because of the arrangement of the impurities in parallel bands. Of these mineral impurities mica is the most noticeable. This variety of stone varies widely in chemical composition, and having been extremely metamorphosed contains a varied assortment of minerals such as biotite, phlogopite, iron pyrites, quartz, calcite, dolomite, and so on. Bands impregnated with dark-colored minerals alternate with others that are white in color and more or less free from the minerals into which the clayey elements enter as essential constituents.

These white bands, ranging in width from a fraction of an inch to several inches, are composed for the most part of grains of calcite and dolomite. Both sets of bands, the dark-colored and the white, generally lie parallel to what is believed to be the original bedding.

Other Districts.—In other areas, such as the Mine Bank, Dulaney, Caves, Worthington, and Green Spring valleys, this limestone has been quarried in the past and is being worked in a small way now, but principally for local building purposes and for manufacture into agricultural lime. These limestone valleys are either anticlinal in character as in "The Caves," or else the limestone occupies valleys occurring on the

flanks of large anticlines with the limestone forming the valley floor, and are flanked on one side as in the case of the Green Spring Valley, by a quartzite ridge, and on the other with hills of Wissahickon schists.

ARGILLACEOUS MATERIALS.—The clayey materials of the eastern Piedmont consist of residual and transported clays and the Wissahickon schist, while the clays of certain of the Mesozoic and Cenozoic formations of the Coastal Plain are also available for use in combination with the eastern Piedmont limestone. These may be considered in the order mentioned, and each briefly discussed with reference to its value in the manufacture of Portland cement.

Residual and Transported Clays.—Residual clays are found throughout the eastern Piedmont, having resulted from the weathering of the underlying rocks. The different deposits may vary widely both in form, size, and chemical composition. The transported clays which are found in this same region occur in the valleys mixed with the residual soil, and along and in the courses of streams. They also vary in the shape and size of the deposit, but on the whole are finer grained, more homogeneous in character, and more uniform in chemical composition. Careful investigation of these materials on the part of those interested in the location of Portland cement plants would doubtless lead to the location of suitable deposits of clays of both kinds.

Wissahickon Schist.—The Wissahickon schist is an argillaceous to siliceous sedimentary formation that was formerly a shale, but has since been altered by metamorphism to a schist. It is characterized by its high content of such metamorphic minerals as garnet, mica, etc. This formation has been described by Mathews and Miller as consisting of “a series of highly micaceous, very schistose, and often crinkled aggregates of quartz, more or less chloritized biotite and garnet, with accessory orthoclase, cyanite, staurolite, etc.” Both its variations in physical character and chemical composition and the stability of its mineral constituents probably make it entirely unsuitable for use in the manufacture of Portland cement.

Mesozoic and Cenozoic Clays.—The most important clayey deposits accessible to the eastern Piedmont district that may be used in the

manufacture of Portland cement in combination with the limestone occurring in the eastern Piedmont lie within the limits of the Coastal Plain. They range in geological age from early Mesozoic to late Quaternary. The formations in which they occur consist of more or less unconsolidated clayey, siliceous, and calcareous sediments that are further characterized by occasional indurated beds.

In numerous instances the Mesozoic and Cenozoic clays, which have been extensively used in manufacture of brick, terra cotta, and other clay products, are found to occur where they may be easily and cheaply won, with the advantage also of being well located for transportation either by water or by rail, and within a comparatively short haul from the deposits of limestone.

The following table gives the order of succession of the formations of Mesozoic and Cenozoic age that occur in Maryland:

TABLE OF COASTAL PLAIN FORMATION.

Cenozoic.

Pleistocene	Talbot.....	} Columbia Group.
	Wicomico.....	
	Sunderland.....	
Pliocene (?).....	Lafayette.	
Miocene	St. Mary's.	
	Choptank.	
	Calvert.	
Eocene.....	Nanjemoy.....	} Pamunky Group.
	Aquia.....	

Mesozoic.

Upper Cretaceous	Rancocas.	
	Monmouth.	
	Matawan.	
	Magothy.	
	Raritan.	
Lower Cretaceous	Patapsco.....	} Potomac Group.
	Arundel.....	
	Patuxent.....	
Triassic.....	Newark.	

All of these formations, except the Newark, which occurs in Montgomery, Frederick, and Carroll counties, are confined to the Coastal Plain and its borders. They are limited on the west by the Piedmont, where

they rest unconformably on rocks much older and of very different character. From the Piedmont they dip gently southeastward toward Chesapeake Bay at the rate of 30 to 50 feet to the mile. It is evident from this, therefore, that the younger formations exhibit their greatest areal distribution along and near the bay shore, while going westward up the estuaries of the bay and the streams that flow into it from the "Western Shore" older and older formations are successively crossed until one encounters finally the more ancient rocks of the Piedmont. These relationships are brought out on the geological map of the State recently issued by the Maryland Geological Survey. With this map one may locate also the limestones of the eastern Piedmont and observe the proximity of these to the different formations of the Coastal Plain.

In selecting the materials for a Portland cement plant in the eastern Piedmont the matter of their proximity of occurrence would be one of the first questions to be considered. The plant would necessarily be located at or near the quarry supplying it with limestone. As the limestone required to operate such a plant would be obtained principally from Baltimore County it would be necessary to get the clayey materials entering into the cement mixture somewhere near at hand. It would be useless, therefore, to consider clay deposits that occurred at considerable distances from the site of the plant unless conditions prevailed making it possible to deliver the clay at the plant at a reasonable cost. The most suitable deposits so far known occur in the Pleistocene, and in the Potomac Group of the Mesozoic.

One of the exposures that may be mentioned where suitable clay for a plant operating on Baltimore County limestone lies to the south of Bodkin Point, in Anne Arundel County. Here the clay can be excavated by steam-shovel and loaded directly into barges and transported up the bay. The thickness of clay deposits exposed along the bay shore in this vicinity varies* from 10 to 30 feet or more in thickness. An analysis of a sample taken by Professor Heinrich Ries ran as follows:

* Md. Geol. Survey, Vol. IV, Part III, p. 396.

ANALYSIS OF PLEISTOCENE CLAY, BODKIN POINT, MD.

Silica (SiO_2)	69.40
Alumina (Al_2O_3)	19.70
Iron oxide (Fe_2O_3)	2.00
Lime (CaO)	.20
Magnesia (MgO)	.60
Alkalies ($\text{Na}_2\text{O} + \text{K}_2\text{O}$)	.62
Ignition	7.85

In the above analysis the ratio of silica to alumina is as it should be, between 3.1 and 4.1; while the ratio of iron oxide and alumina to silica is also satisfactory. The amount of magnesia present is insignificant and non-injurious, being many times less than 3 per cent., the allowable upper limit.

Of the Potomac Group the Arundel formation probably affords the largest deposits of clay adapted for use in the manufacture of Portland cement. A very large supply occurs at Monumental on the Baltimore and Ohio Railroad. Most of the clay here* Ries describes as being bluish-gray in color, while the upper portions are often oxidized to red and yellow. There are also some dark organic facies in parts of the bank.

Near Curtis Bay Junction the Arundel clay is also well exposed. Analyses made on material collected here by Ries gave the following results:

ANALYSES OF ARUNDEL CLAYS NEAR CURTIS BAY STATION.

	I.	II.
Silica (SiO_2)	59.70	71.55
Alumina (Al_2O_3)	27.00	17.70
Iron oxide (Fe_2O_3)	2.10	2.25
Lime (CaO)	.60	.60
Magnesia (MgO)	.52	.86
Alkalies ($\text{Na}_2\text{O} + \text{K}_2\text{O}$)	1.96	.42
Ignition	8.20	6.50
Total	100.08	99.88

Analysis I. Md. Geol. Survey, Vol. IV, Part III, p. 431.

Analysis II. Md. Geol. Survey, Vol. IV, Part III, p. 433.

Of the two analyses quoted above No. I, though all right in other respects, is too high in alumina. It might, however, be used to advan-

* Md. Geol. Survey, Vol. IV, Part III, p. 434.

tage by mixing it with a limestone of the composition of the "alum stone" at Texas, Md., in which the content of alumina is very low. The clay represented in analysis No. II, is not so high in alumina as No. I, but in this respect is slightly low. In Portland cement manufacture a clay having the composition shown in analysis No. II would prove more satisfactory than a clay analyzing like No. I. Highly aluminous Portland cements are generally discredited, and very properly, too, especially if they are intended for marine work. Many of the clays of the Patapsco formation of the Potomac Group are often sandy. In some of the deposits, however, analysis shows, as in the case of the one quoted below, that the constituents are suitably proportioned and adapted for use in Portland cement:

ANALYSIS OF PATAPSCO CLAY, BACON HILL, CECIL COUNTY.

Silica (SiO_2)	65.70
Alumina (Al_2O_3)	20.30
Iron oxide (Fe_2O_3)	1.00
Lime (CaO)	3.50
Magnesia (MgO)	1.44
Alkalies ($\text{Na}_2\text{O} + \text{K}_2\text{O}$)	0.62
Ignition	7.60

Total 100.16

ANALYSES OF LIME AND CEMENT MATERIALS.

BALTIMORE COUNTY.

Name of limestone.	Map No.	Nearest town.	Silica (SiO_2).	Alumina (Al_2O_3).	Iron (Fe_2O_3).	Lime (CaO).	Magnesia (MgO).	Ignition.	Total.	CaCO_3 .	Analyst.
Marble.	1	Cockeysville.	9.79	5.62	...	39.56	6.94	38.69	100.60	70.6	T. M. Price.
"	2	"	2.33	0.00	...	52.08	2.39	43.25	100.05	92.5	Jas. Higgins.
"	3	"	0.44	1.22	Tr.	30.73	20.87	47.07	100.33	55.0	J. E. Whitefield
"	4	"	5.57*	0.40	...	29.08	20.30	44.26	99.61	47.0	E. A. Schneider
"	5	"	2.33	1.55	...	29.30	20.80	46.00	99.98	52.3	H. J. Patterson
"	6	"	3.04	1.46	.76	31.33	18.66	44.94	100.19	56.1	O. C. Bransky.
"	7	"	3.24	2.06	.84	32.20	17.52	44.87	100.83	57.6	O. C. Bransky.
"	8	"	6.73	2.62	.56	29.64	19.05	41.90	100.60	52.8	O. C. Bransky.
"	9	"	3.88	3.23	1.03	30.68	17.61	44.26	100.69	55.0	O. C. Bransky.
Alum stone.	10	Texas.	.36	.20	...	55.72	.19	43.77	100.24	99.5	Zies & Schmidt.
"	11	"	2.10	.61	...	53.70	.61	42.54	99.56	95.8	Zies & Schmidt.
Magnesia stone.	12	"	6.65	2.08	...	33.58	15.34	41.32	98.97	60.0	Zies & Schmidt.
Blue stone.	13	"	4.90	1.11	...	50.92	1.34	41.03	99.30	90.9	Zies & Schmidt.
Marble	14	"	2.00	0.00	...	52.08	2.39	43.44	99.91	92.6	R. S. Williams

* Insol.

Summary and Statistics for the Eastern Piedmont.

The calcareous deposits of the eastern Piedmont consist exclusively of thoroughly crystalline marbles which vary in composition from pure lime carbonate to dolomite, and from these pure stones to calcareous schists through the progressive admixture of argillaceous impurities.

The industry based on the working of these materials is practically limited to Baltimore County, about three centers: Cockeysville and Texas, Summerfield, and Glyndon. Of these only the first is of much importance. The quarrying of marble as a building stone is limited almost entirely to Cockeysville. The production of lime is more widespread, although the largest production is from the Texas region. Other smaller operations are reported from various points in the region: From Hess, in Harford County; Fulton, Highland, and Clarksville, in Howard county; and from Dover, Butler, Glyndon, and Texas in Baltimore County. At many points old hillside kilns may be seen which are used intermittently with little or no record of the production.

The total value of the marble and lime produced in the eastern Piedmont in 1908 was \$137,561, about half of which was for the lime burned for agricultural and building purposes. Stone for flux was formerly quarried at Texas, but at present at least nine-tenths of the limestone used for fluxing purposes is shipped into the State from West Virginia.

LIST OF LIME AND MARBLE OPERATORS IN THE EASTERN PIEDMONT OF MARYLAND.

BALTIMORE COUNTY.

OPERATOR.	OFFICE.	QUARRY.
Baltimore County Marble & Trading Co.	Baltimore	Summerfield.
Beaver Dam Marble Co.	"	Cockeysville.
Bluemont Stone Co.	Baltimore	Whitehall.
Councilman, Charles A.	Glyndon	Glyndon.
Cockey, Ed. A. & Son.	Owings Mills	Gwynnbrook.
Ditman, Wm. C.	Texas	Texas.
Lindsay, Wm. P.	Texas	Texas.
Myers, Wm. F.	Boring	Dover.
Price, M. Bissel (Miss).	Cockeysville	Cockeysville.
Turnbaugh, T.	Boring	Dover.

HOWARD COUNTY.

Baker, G. F.	Marriottsville	Marriottsville.
Walters, G. Dallas.	Fulton	Fulton.
Zepp, P. P.	Marriottsville	Marriottsville.

WESTERN DIVISION OF THE PIEDMONT.

The western division of the Piedmont has been separated from the eastern in earlier descriptions by Parrs Ridge. In the present discussion, however, in order to include the crystalline limestones of the headwaters of the Gunpowder River, the northern portion of the line begins near the northeast corner of Carroll County and extends thence southwesterly uniting with the more generally accepted line near Westminster. That portion of the western Piedmont with appreciable amounts of limestone is included in the western part of the Westminster, the major portion of the Taneytown, and parts of the Mount Airy, Ijamsville, and Emmitsburg quadrangles, i. e., in Carroll and the northeastern part of Frederick counties.

The western division of the Piedmont in Maryland is marked topographically, especially in its northern portion where the limestones occur, by a broad upland basin sloping gently to the west. Across this region trend four major ridges of moderate elevation, separated by broad, undulating valleys. These ridges, respectively, from east to west, may be designated as Parrs Ridge, Mt. Vernon Hill, Mt. Zion Ridge, and Johnsville Ridge. A minor ridge, marking the western limits of the more crystalline rocks, borders the Frederick Valley. These ridges owe their elevation to the presence of altered acid and basic volcanics with quartzite in at least two of them.

The drainage west of Parrs Ridge is accomplished by Double Pipe Creek and its tributaries, Israels, Sams, and Turkey-foot creeks. These streams cut through the resistant quartzitic and volcanic ridges and wend their way westward approximately at right angles to the general trend of the limestone valleys which furnish small feeders. The waters of these streams finally mingle with those of the Monocacy.

Geology.

The geological features of the western Piedmont may be summarized as follows: The general trend of the rocks of this region is in every respect similar to that of the rest of the Piedmont on the east and the Appalachian Mountains on the west. The result of the movements which

have given these rocks their present trend is particularly well exhibited in the mapping of the limestones. In the southwestern part of the area the strike is N. 25° to 30° E., but about 4 miles south of Union Bridge the strike of the limestones turns to the northward until in the vicinity of that town the strike ranges from N. 5° to 15° E. Going northeastward, however, from Union Bridge the limestone again appears to strike more strongly to the east and comes to have a general strike of N. 20° to 30° E.

It is thus clear that this region has experienced the same general movements that have affected the rocks of the eastern Piedmont and caused the uplift of the Appalachians further west. The trend of the rocks of the three regions is closely parallel and concentric in arrangement to the same seat of orogenic action, located near and to the southeast of Baltimore.

The relationships existing between the topography, geology, and general structure of this region are most pronounced. With the exception of one or two places where limestone outcrops on and near the hilltops the greater part of the limestone occupies the valley floors. The prominent ridges and the smaller hills are made up mostly of altered volcanics, with quartzites found here and there associated with them. The structure of the valleys in which limestone occurs is generally anticlinal, while that of the ridges is synclinal, and each is more or less overturned to the westward. In both instances the folding has been most complex, and is best exhibited in the minor foldings of the slaty metarhyolites and argillaceous limestones, the latter occurring near and northeast of Linwood.

In the general anticlinal structure of the valleys minor synclinal folds sometimes appear, and often are found infolding the metamorphosed volcanics. Likewise the synclinal ridges exhibit at times small anticlinal folds that result occasionally in exposing at the surface small areas or knobs of limestone. Consequently the anticlines in this section often partake more or less of the nature of anticlinoria and the synclines of synclinoria. Both exhibit smaller foldings in the shape of smaller anticlines and synclines. These smaller flexures are subordinate

to the major folding, and a correct cross-section would therefore represent and show both compound and doubly compound flexures, the extent of the latter depending upon the amount of minor folding.

While the characteristic feature of the structure of the western Piedmont is the prevailing dip eastward and the sharp folding of the rocks into anticlines and synclines, which are overturned to the west, there is good reason to believe that far more faulting has occurred than has heretofore been suspected, although little field evidence has yet been found to indicate the exact location and actual occurrence of such faulting. It has been suggested that this whole region, structurally, is a great fault block which has been faulted up parallel and close to the arbitrary line taken as delineating the western Piedmont on the east, while at the same time similar displacement occurred on the west, roughly paralleling the eastern boundary of the Frederick County Shenandoah limestone, and that the more apparent folds of the region have been imposed subsequent to the faulting.

TYPES OF ROCKS.—Four distinct types of metamorphic rocks, each with its more or less marked varieties, are readily recognized in this western Piedmont region. These are limestones, quartzites, slates, acid, and basic volcanics.

Limestones.—In this region there are three different kinds of limestone, (1) the white crystalline limestone, (2) the variegated limestone, and (3) the argillaceous limestone.

The *white crystalline* limestone is much the most important of the three varieties named, both in distribution and in value. It is a fine-grained crystalline limestone, or marble, that ranges in color from cream to pure white. Analyses made on different samples show a fair degree of uniformity except in the content of magnesia. This varies from a trace to 15 or 20 per cent. The limestone contains few accessory minerals, the principal of which are diopside, tremolite, barite, manganese ores, pyrite, chalcopyrite, bornite, and malachite.

In the case of a number of occurrences to be mentioned later this stone is found unusually free from impurities and suited, not only for making lime for agricultural use and lime to supply the building trades, but for



FIG. 1.—STAUB QUARRY, LITTLE PIPE CREEK, NEAR WAKEFIELD, CARROLL COUNTY.



FIG. 2.—RINEHART QUARRY, SOUTH OF UNION BRIDGE, FREDERICK COUNTY.

VIEWS OF WESTERN PIEDMONT QUARRIES.

all purposes for which an unusually high-calcium limestone is required. Furthermore, this white crystalline limestone may also be employed to advantage in structural work. It takes a good polish and but for lines of weakness that have been developed as the result of pressure it would be unexcelled as a marble for building and decorative purpose and for fine statuary work as well. In the few instances where the rock has not suffered seriously from the sharp folding it may prove valuable for all these purposes.

The *variegated limestone* accompanies the white variety just described, and occurs in zones where the latter has been fractured and recemented. Locally, it is referred to as "calico limestone" in reference to the fact that it is composed of both white and colored fragments, the latter ranging in color from nearly red to a faint pink. The reddish to pinkish parts of the stone are due to the presence of small amounts of manganese and associated iron. These metals seem to have been introduced from below by uprising solutions carrying also in certain cases small amounts of copper. The presence of copper in this variety of the limestone has led to a considerable amount of prospecting and exploitive work which so far has proved disappointing from a commercial standpoint.

The copper ores, which are principally bornite and chalcopyrite, are, however, not wholly confined to the limestones of the characteristic variegated sort. These variegated limestones are always present in the more fractured zones of limestones; but the copper ores, as in the old Liberty Mine southwest of Johnsville, where the limestone carried .75 to 1 per cent. of metallic copper, are found also impregnating portions of the accompanying white crystalline limestone of the type first mentioned. It is interesting to note, moreover, that in these fissured and fractured zones the limestones are also usually inclined to be high in their content of magnesia, and where copper is present are found to be in close association with igneous rocks.

The variegated limestones, as might have been inferred, are also crystalline in character. When cut and polished they form an exceptionally attractive decorative stone. However, they have never been extensively worked for this purpose, although this might be done by em-

ploying suitable channeling machines in certain instances where the rock may be obtained in good marketable shape. The principal defect of the rock is inherent to its manner of origin. The lines of weakness developed as the result of the crushing and fissuring action experienced, still remain in spite of the recementing of the parts and might interfere seriously in the preparation of this stone for actual use.

In chemical composition these variegated crystalline limestones, or marbles, are sometimes very high in calcium carbonate and low in impurities, as shown by the following analysis. Generally, however, they contain 4 or 5 per cent. of magnesia, with varying amounts of silica and alumina.

The following is an analysis of a sample high in calcium carbonate:

ANALYSIS OF VARIEGATED LIMESTONE, UNION BRIDGE.

	No. 15.
Silica (SiO_2)	1.42
Alumina (Al_2O_3)	.74
Iron oxide (Fe_2O_3)	
Lime (CaO)	53.04
Magnesia (MgO)	1.49
Manganese (MnO)	.10
Ignition	43.20
Total	99.99

The *argillaceous limestone* overlies the white crystalline limestone described on a previous page. It varies in color from gray to dark blue. The folding and fracturing which the white crystalline limestone and all the rocks of this region have experienced is in this third type of Piedmont limestone clearly revealed. The minor folding exhibited in the small anticlines and synclines are all more or less compressed and overturned westward.

Besides having been profoundly folded this rock has also been greatly fissured and is streaked with veins both of quartz and calcite. It appears to represent a facies of the white crystalline limestone formation, to which it is superjacent, resulting from the introduction during the period of limestone deposition of land-derived sediments.

Quartzites.—The quartzite of this district is best exposed in the Johnsville Ridge. It is composed of fine grains of quartz originally deposited, of course, as sand that accumulated to form a sandstone. Subsequently dynamic metamorphism has converted the sandstone into a hard quartzite. Quartz veining and secondary cleavage that may be mistaken for true bedding also evidence the tremendous stresses to which it has been subjected. This may be of the same age as the Weverton, which it resembles, but its stratigraphic position was not satisfactorily established during the field study of the nearby limestones.

Slates.—The slates of the western Piedmont, referred to in earlier publications as phyllite, are metamorphosed representatives of normal sedimentary deposits and of igneous rocks, both tuffs and lavas. The relations between the two have not been determined satisfactorily, but in places they seem to grade into each other, suggesting that some, at least, were formed by the contemporaneous deposition of volcanic ash and land-derived materials under subaqueous conditions. The deciphering of their relationships and their relative areal distribution requiring accurate and detailed topographic maps necessitated a postponement of the solution of this question until such maps are available.

That many of the slates are metamorphosed volcanics is shown by the presence of little feldspar crystals, which may be seen by the naked eye, and still better with the aid of a good magnifying glass, and by the relatively high content of the alkalis shown by the analyses below. The content of alkalis of two slates found in contact with the white crystalline limestone, one a typical gray with slight pinkish tint, and the other a characteristic purple, are as follows:

ALKALI DETERMINATIONS OF VOLCANIC SLATES, UNION BRIDGE.

	I.	II.
Soda (Na_2O)	.73	1.51
Potash (K_2O)	6.02	4.18
Total	6.75	5.69

I. Gray slate No. 8, Clemson Slate Quarry.

II. Purple slate, Union Bridge.

The slates of this region differ greatly in the degree of their fissility. The cleavage in some cases is so highly developed, as at Ijamsville, that they have been worked occasionally for more than a century to meet local demands for roofing slates. Attempts have been made to establish a more general quarrying industry, but this has failed since the finished slates lack the "ring" assumed by the trade to be an evidence of permanency. Long exposures on local structures have proven their permanency, but it is improbable that an industry can be established.

Basic and Acid Volcanics.—In addition to the slates of undisputed igneous origin, two other types of igneous rocks that may be readily distinguished in the field are the basic and acid volcanics, the former allied in composition to basalts and diabases and the latter to rhyolites. They are harder and less schistose than the slates and have a fine-grained ground mass in which small crystals of quartz and feldspar, though rarely very prominent are, in most instances, clearly discernible. They are the chief ridge makers of the region. Megascopically, they are exact analogues of certain of the acid and basic eruptives occurring in the Monterey district and that portion of South Mountain which lies in Franklin and Adams counties, Pennsylvania, which have been mapped and studied both in the field and laboratory by Dr. Florence Bascom.*

The basic volcanics are much more widely distributed in the western Piedmont than the acid volcanics, as is also the case in the Monterey district. The age relationship between them has not been satisfactorily determined in either district. Both are found intimately mingled, and the field evidence points to the occurrence in both regions of several sources of lava flow.

In the western Piedmont the chief supply of basic and acid lava was poured out from volcanic vents situated, respectively, in the northern and southern portion of the region.

The *basic volcanics* or "greenstones" of the western Piedmont are characteristically green to greenish-gray in color, owing to the presence of epidote and chlorite. Besides, as has been pointed out, having ana-

* U. S. Geol. Survey, Bull. No. 136.

logues in the Monterey districts the more metamorphosed representatives are strikingly similar to the Catoctin schists which, according to Keith,* have resulted from the alteration of diabase, the latter originating as "a flow of lava along the surface." He describes the Catoctin schist as follows: "The schist was originally a diabase or volcanic rock, composed of crystals of feldspar, pyroxene, olivine, magnetite, and ilmenite. The original massive rock was altered by tremendous pressure and distortion which accompanied folding, so that pyroxene became chlorite, magnetite, and quartz, and the feldspar was partly altered to quartz, chlorite, and muscovite. The new minerals were arranged parallel to one another, and thus the rock became a schist, characterized by the ease of splitting along these minerals." This description would apply equally well as to the origin, metamorphism, and physical characteristics of most of the crumpled schistose, slaty, and epidotic basic volcanics of the western Piedmont.

The basic volcanics of the western Piedmont though usually schistose, compact and fine-grained, and specked with irregularly arranged crystals of quartz and feldspar sometimes occur also with a prominent amygdaloidal structure. The rock in this case is pitted with round, oblong, and irregular-shaped cavities rimmed with iron oxide, which are either empty or partially filled with the minerals calcite, epidote, etc. Because of these features the local name "honey-comb" rock has been adopted, a term not so scientific as it might be, but nevertheless thoroughly descriptive of the characteristics just mentioned.

The *acid volcanics* of the western Piedmont region may be distinguished in the field from the more basic rocks by their difference in color, which ranges with intermediate shades from blue to gray and purple. These rocks occur intimately associated with the basic volcanics or "green-stones" in the northern part of Frederick and Carroll counties, and because of the lack of satisfactory maps the two have not been separated in mapping. Southwestward from Union Bridge to Liberty the acid volcanics increase in prominence and in areal distribution, showing that

* U. S. Geol. Survey, Geologic Atlas, folio 10.

they were originally poured out from one or more volcanic vents to the southward, while on the other hand the basic eruptives originated from a seat of volcanic activity to the north.

The basic and acid volcanics of the western Piedmont lack many of the different phases of crystallization that are exhibited by the eruptives in the Monterey district, being on the whole less porphyritic. When phenocrysts do occur they are smaller and embedded in a finer-grained ground mass. These rocks also give less evidence of flow structure and, so far as has been seen, no evidence of lithophysal or spherulitic textures. If the latter were ever present in the rocks they have either been overlooked or entirely destroyed by the development of the schistosity. As a whole, the volcanics of the Piedmont seem to have suffered more metamorphism than the similar rocks exposed in the South Mountain area, and are consequently more schistose and sheared than their representatives farther west. Nevertheless, there exist large volcanic areas where the rocks of the two regions are practically indistinguishable.

The ancient basic and acid volcanics of the Monterey district are succeeded in the western and central part of the area by the Monterey sandstone. Dr. Bascom thinks that this sandstone, which is Cambrian in age, was deposited upon the underlying eruptives. This would, of course, make the age of the eruptives pre-Cambrian.

GEOLOGICAL SEQUENCE.—The four types of rock described are found overlying each other near the Sauble Quarry on the south end of the Johnsville ridge east of Johnsville. Here the order of superposition from top to bottom is:

Altered volcanics,
Slate,
Limestone,
Quartzite.

If this succession is the normal sequence then all of the rocks are pre-Cambrian, provided the volcanics of the Monterey and western Piedmont represent the same formation as they are supposed to do. Such an interpretation makes the limestone and quartzite older than any similar rocks known in the State.

There are, however, many field observations against this simple interpretation. At several points shales or slates, presumed to be the equivalent of the nearby Martinsburg shales, appear to be interbedded with volcanics, suggesting that some of these, at least, are Ordovician rather than pre-Cambrian. At nearly all points the contact between the limestones and the superincumbent volcanics is not a contact of conformable beds. If this were the case one might expect to find evidences of contact action in the limestones due to the pouring over it of molten lavas. Moreover, the contact plane is often polished and slickensides, proving that it has been a plane of movement and faulting.

Two explanations may be given to the phenomena as now known:

1. The volcanics of the Piedmont may be, in part, at least, of Ordovician age, in which case the limestones may represent metamorphosed equivalents of the nearby Shenandoah group, or

2. The volcanics may be pre-Cambrian and overlie the limestones through thrust faulting along a plane near the upper limit of the limestones, in which case the limestones may be of Loudon or Shenandoah age.

The final solution of the problem must await detailed mapping of the area on satisfactory base maps. The discussion of these formations as sources for material in the manufacture of lime and cement will not, however, be affected by the ultimate solution of the question of their geological age.

TRIASSIC.—Overlying the older rocks of the western Piedmont and the shales, limestones, and quartzites of known Ordovician and Cambrian age in the Frederick Valley are the much younger "red beds" of the Newark formation. Deposits of this age and character are known from Connecticut southward as far as the Carolinas. Whether these rocks were laid down as a continuous formation or in isolated areas is not known. It is generally agreed, however, that they are of shallow-water formation, and that they were laid down in estuaries or lagoons within the continental area.

In Maryland, as elsewhere, the formation consists of red and gray

sandstones and shales, with occasional intercalated beds of calcareous conglomerate or "calico marble."

The Newark beds enter the State from the north between Emmitsburg and Taneytown, with a breadth of 14 to 15 miles, and narrow rapidly southward until they are interrupted by erosion at a point west of Frederick, exposing the underlying Shenandoah limestones faulted upon the Cambrian rocks of Catoctin Mountain. Southward from this point they widen gradually, extending with a slight break in the Valley of the Monocacy into southwestern Montgomery County.

The Newark formation lies unconformably on the Piedmont limestones and associated altered volcanics which are exposed in the northwestern part of the Taneytown quadrangle wherever the Newark formation has been sufficiently eroded. The volcanics, Shenandoah limestones, Martinsburg shales, and Piedmont limestones all pass beneath this formation.

Distribution of Lime and Cement Materials in Western Piedmont.

PIEDMONT LIMESTONES OF CARROLL COUNTY.—The limestones of Carroll County all belong to the western Piedmont type. They occur in narrow anticlinal valleys striking northeast and southwest with a general flexure in their trend to more nearly east and west in the vicinity of Union Bridge.

The exposures in the northeastern corner of the county, along the Hanover Branch of the Western Maryland Railroad, are small and unsatisfactory for large scale operations in lime or cement manufacture. Stone has been quarried and burned for local consumption in the vicinity of Miller, Alesia, and Lineboro, but the quality and quantity are both unsatisfactory. Both north and south of the latter point they have been exposed in mining for iron ore with which the limestone is here associated.

Small lenses of limestone occur southwest of Lineboro in the Bachman Valley, but no deposits of appreciable size are encountered until in the vicinity of Westminster.



FIG. 1.—LIMESTONE QUARRY OF TIDEWATER PORTLAND CEMENT COMPANY, UNION BRIDGE.

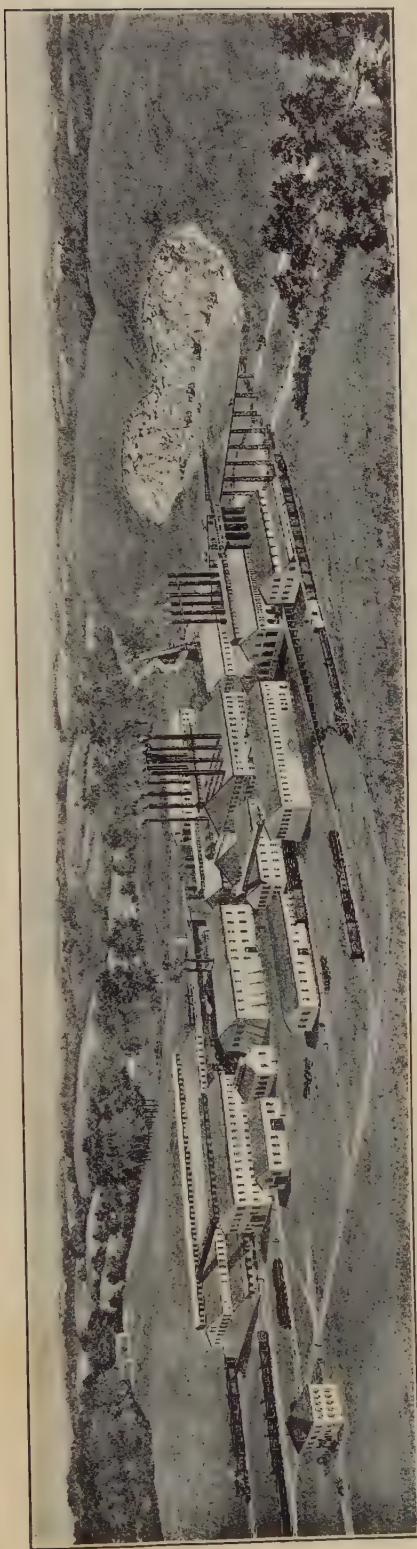


FIG. 2.—VIEW OF PROPOSED PLANT OF TIDEWATER PORTLAND CEMENT COMPANY, UNION BRIDGE.
VIEWS OF QUARRY AND PLANT OF THE TIDEWATER PORTLAND CEMENT COMPANY, NEAR UNION BRIDGE, CARROLL COUNTY.

The areal distribution of the exposure is represented in the accompanying map, and where samples have been taken for analysis the location is indicated by numbers corresponding to those assigned the analyses in the accompanying list. By referring to the map and analyses it is possible to gain an accurate idea of the composition of the stone at a given locality.

North of Westminster is the *Orndorf Quarry*. This is reached by the road from Westminster to Stoner, and is about 3 miles north of the former. This is a small quarry, and while a considerable quantity of stone has been quarried in the past, and the lime made from it sold chiefly for agricultural purposes, it is capable now of very little further development because of its heavy overburden of volcanics.

The limestone occurrences within the limits of the northern half of the Taneytown quadrangle though geologically important are, however, from a commercial viewpoint, insignificant. Their distribution is limited and is restricted to the vicinity east of Mayberry and west of Silver Run.

Quarries have been opened and operated on white crystalline limestone both to the north and the southwest of Westminster. Those located in the latter direction are centered about Spring Mills, which is on the Western Maryland Railroad about $1\frac{1}{2}$ miles west of Westminster. There are four quarries here, but only two are in operation. Both of these are small and neither is capable of large development because of the heavy overburden of soil and volcanics. The first of these to be considered is the *Geo. W. Albaugh Quarry*, which is situated on the north side of the Western Maryland track $\frac{3}{4}$ of a mile east of Spring Mills, or, in other words, between Spring Mills and Westminster. The geographic position of the quarry and the composition of the stone are both indicated by "No. 1" on the map and in the table of analyses, respectively. By consulting the reference number in the table of Carroll County analyses, it will be seen that so far as the quality of the limestone is concerned it would fully meet the requirements for use in the manufacture of Portland cement. The quantity of material that could be economically quarried would, however, be insufficient. On the northwest side of the quarry, which would be the natural direction for development, the white

crystalline limestone, exhibiting here and there bands of blue limestone, is capped by a heavy cover of volcanics that forbids much further work in this direction.

The quarries located at the points Nos. 2 and 3, respectively, northeast and southwest of Spring Mills, have long since been abandoned because of the small exposures, and because, too, of the heavy overburden of volcanic material and the consequent high cost of quarrying at both these places. The quality of stone at each of these small quarries is such as to make it adapted to mix with a suitable shale in the manufacture of Portland cement, but in both occurrences there is a deficiency in the quantity of the material susceptible of economic working.

The only quarry to the southeast of Spring Mills and Warfieldsburg, that is in operation, is known as the *Roop Quarry*. This is opened on the white crystalline limestone, which is much fissured and accompanied by some limestone of the "calico" variety. The former forms the floor of the little valley that extends nearly all the way from Spring Mills to Warfieldsburg. The quarry is situated on the west side of this valley and is opened under the brow of the hill, an outlier of Parrs Ridge, that rises in this direction. The working face is from 15 to 35 feet high, with a cover, which is mainly at the south end of the quarry, ranging from 10 to 18 feet in thickness. The dimensions of the quarry are as follows: 85 feet northeast and southwest and 30 to 50 feet northwest and southeast. The hard, pink-streaked white limestone that is obtained here and used mostly for manufacture into lime is high in magnesia, containing 15.30 per cent. of magnesia (see analysis No. 4).

Of the small quarries that have been opened east of Wakefield and west of Parrs Ridge, the only one perhaps worth mentioning is situated about a mile nearly due north from Avondale, and about midway between Copps Branch and the road passing along the west flank of Parrs Ridge. This is known as the *B. F. Shriver Quarry*, and its precise location on the map is indicated by the number 5.

The white crystalline limestone of this quarry is intensely fissured and is overlain on the west by a thick mantle of volcanic rock of the amygdaloidal or "honey comb" type, prohibiting, except at a considerable

cost, any further extensive development of this side of the quarry. The Shriver Quarry is no exception to the fact, to which attention has already been called, that when the limestones of this region occur much fissured and intimately associated with volcanics, they are usually high in magnesia. The content of magnesia in the Shriver Quarry is slightly over 10 per cent. (see analysis No. 5).

William Carbaugh's Quarry (No. 6) is located just outside of the town of New Windsor on the south side of the south fork of Pipe Creek and east of the small stream that enters the creek within a stone's throw north of the quarry. Here the limestone is high in magnesia, as is found to be the case nearly everywhere, that the western Piedmont limestone is either greatly fissured or is closely associated with the less altered of the volcanics. The limestone here lies between the volcanics. Where the former is superjacent to the volcanic material on the west there is a marked difference in the dip of the two rocks. The dip of the limestones is 15° E. while that of the planes of schistosity of the volcanic is 70° to 80° E. In the old, abandoned quarry due west, located on the south side of the juncture of the road from the quarry to the turnpike, this volcanic is again in contact with the limestone, which, as previously stated, lies between beds of altered rock of igneous origin. The structure here is strongly suggestive of step faulting, accompanied and followed by folding.

Two other quarries opened on white crystalline limestone are located on the northwest side of the ridge that extends from New Windsor northward by Wakefield. They are situated on the west bank of Little Pipe Creek. The first, the Geo. R. Staub Quarry (No. 11), being about $\frac{3}{8}$ of a mile north of the juncture of Turkey Foot Run and Pipe Creek. The other, the small quarry (No. 12) owned by Dennis A. Smith, is nearly opposite the point where the run flows into the creek.

The *George R. Staub Quarry* (No. 11) is located but a short distance up the creek from the Smith Quarry. In the past the Staub Quarry has been extensively worked and the stone burned into lime, but it now lies idle, chiefly because of the expense attendant upon removing the overburden of residual soil which varies in thickness from 3 to 15 feet. The

length of the quarry in the direction parallel to the creek is close to 300 feet, and ranges in width, east and west, from 50 to 150 feet. The average breast is about 22 feet. As can be seen from the Carroll County table of analyses the stone obtained here is low in iron, alumina, and silica but high in magnesia.

The stone obtainable from the *Dennis A. Smith Quarry* (No. 12) is low in magnesia and would, but for its distance from the railroad, the low-working face, and the expense of quarrying, be suitable for manufacture into Portland cement. The breast of stone is about 15 feet high and is covered above with nearly 3 feet of residual soil. It dips 50° E., and burns into a very good grade of lime.

At all of the quarries south of New Windsor the limestone is of the white crystalline variety, and as usual is so greatly fissured because of the stresses, pressure, and distortion it has experienced, that the original bedding planes and their direction of dip are partially, if not wholly, obscured by other planes and fissures superinduced by the forces just mentioned. Nevertheless, in spite of the secondary cleavage, the original stratification planes, if they have been correctly identified, may be said to dip from 10° to 15° east.

About a mile and a half farther up the narrow limestone valley drained by the small stream passing the Carbaugh Quarry there is another quarry that has been opened and operated on a small scale, which is known as the *A. Rupp Quarry*. Its position on the map is shown by the number 7.

A quarter of a mile, more or less, down the stream from the Rupp Quarry is an old opening where most of the stone susceptible of being worked economically has been removed. Neither this quarry nor the Rupp Quarry, where the quality of the stone is very good indeed, is capable, however, of yielding a large tonnage of stone without the removal of a thick overburden on all sides which would make the cost prohibitive were it attempted to work either place much more extensively than at present. The breast of stone, moreover, in both these quarries is low, ranging from 10 to 20 feet in height. This might be increased by deepening the quarries, but in either instance any anticipated

advantage that might result would be more than counterbalanced by the extra expense so entailed.

Limestone is exposed both to north and south of Linwood, and has been worked at both the quarry sites indicated by numbers 8 and 9. These quarries, however, at present are not in operation. The former, *Haines Quarry*, is situated, as shown, on Little Pipe Creek just to the north of Linwood. The limestone is here hard and white and high in magnesia, though low in silica, alumina, and iron. The quarry may be seen on the north side of the road directly west of Linwood Station. At the Haines Quarry the breast of stone is 25 to 30 feet thick. Formerly it was quarried and burned into lime, but during the past few years the quarry has lain idle. It is stated that the quarry was abandoned owing to the fact that the stone is hard and expensive to quarry, and for the further reason that the lime produced failed to meet with favor among those using it for agricultural purposes.

A small quarry has been opened, but is idle at present, on the white crystalline limestone exposed on the *Shriver* place, southwest of Linwood, at the point (No. 8) indicated on the map, with a breast of about 20 feet. This working face, however, might be increased with further development. Analysis shows that the rock here is too high in magnesia for Portland cement, though fairly suitable for making agricultural lime.

The limestones up Roop Branch, to the east of Clear Ridge, have been quarried at different points, but the stone being highly argillaceous burns to a very unsatisfactory grade of lime. The only quarry now in operation on this type of limestone is situated about a mile and a quarter east of Uniontown, and about an eighth of a mile south of the Uniontown-Westminster road. The quarry and two kilns (No. 10) are owned by Fielder G. Gilbert. The limestone in the *Gilbert Quarry* is blue to gray in color and streaked with veins, both of quartz and calcite, the latter usually predominating. The limestone is extremely shaly and the intense stresses to which in the past it has been subjected are indicated by the complicated minor folding and veining to be seen throughout the quarry. The working face at the south end of the quarry, where the rock passes upward into beds increasingly argillaceous and shaly, is a little

over 20 feet. The lime produced, although of a low grade, meets with a ready sale for agricultural purposes to supply a local demand, but only because of the distance of the surrounding country from better limestone deposits and from the railroad, and the consequent greater expense of obtaining a lime of better quality.

Argillaceous limestone, extremely shaly and impure, occurs on the farm of *Mr. Frank Englar* (No. 13) north of the Western Maryland Railroad and about midway between Union Bridge and Linwood. With this exception all of the limestones near Union Bridge are of the white crystalline variety accompanied here and there by the variegated type. The location of the quarry where this shaly limestone has been worked and burned to a limited extent into lime for agricultural use, in spite of its impurities, is indicated on the map by the number 13, opposite which, in the table of analyses, may be found the composition of the sample.

Northwest of the station at Union Bridge limestone again is well exposed on the *Clemson place*, from the points 15 to 17, shown on the map. It is here a hard white limestone that has been much fissured and contains at unequal intervals infolded fragments of altered volcanic. The working face above the level of the meadow-land which lies between it and Sams Creek ranges from 15 to 30 feet. With the exception of sample 17, which represents the stone in the small, abandoned quarry just west of the Clemson house, the rest of the limestone, as may be seen by consulting the table of analyses, is high in magnesia. It would be unsuited for Portland cement. It is perhaps best adapted for use as ballast or as road metal, and for these purposes it could probably be profitably quarried.

PIEDMONT LIMESTONES OF FREDERICK COUNTY.—Limestone lenses, similar in all respects to those of Carroll County, continue to occur southward, extending across Frederick County in a gradually narrowing zone from Sams Creek on the north, through Liberty and Unionville, to the vicinity of New Market on the south. With a single isolated exception, near Park Mills, no crystalline limestones of the western Piedmont type are exposed south of the main line of the Baltimore and Ohio Railroad.

The areas of exposure trend in a northeast and southwest direction of long elliptical or irregular shape, and are found in greatest breadth and abundance along a line following the road from east of Woodsboro, through Liberty, to a short distance east of Unionville. The limestone areas on the northern border of the county, near Union Bridge, are the only ones situated near the railroad, and therefore potentially available for cement manufacture. The deposits more removed from the lines of transportation, while unavailable for larger operations acquire an increased value as a source of stone for lime burning to meet local demands for agricultural purposes.

Some of the purest limestone in the State is found in the vicinity of Union Bridge. This is confined chiefly to a narrow belt passing east of the town, where the limestone is from 100 to 150 feet thick and dips about 20° east and strikes N. 15° to 20° E. It is worked at the Wolfe Quarry of the Tidewater Portland Cement Company on Sams Creek; and at the Haines Quarry about a half a mile to the northwest of Union Bridge. Between these points the overburden of residual soil is, however, too thick to make the opening of a quarry profitable.

The *Wolfe Quarry* is located in Frederick County (Nos. 1-5) about $\frac{1}{4}$ mile east of where the Johnsville Turnpike, leading south from Union Bridge, crosses Sams Creek. The quarry, when visited, was about 165 feet in length in a north and south direction, and about 130 feet wide, measured east and west. The working face of pure white crystalline limestone was from 35 to 40 feet high. The limestone in this quarry dips 20° east, and on the eastern side of the quarry passes under a heavy mantle of purplish to gray slate which forbids extensive development in this direction. In the northwest end of the quarry variegated limestone is seen accompanied by infolded chloritized slate. Here also it was observed that the stone contained a small amount of malachite.

Throughout the Wolfe Quarry the limestone is very much fissured. It breaks and shatters easily under the hammer, but this is due to the lines of weakness that were developed during its geological history because of the stresses and distortion that it has undergone as the result of the folding and faulting characterizing the structure of this entire section.

Analyses (1-5), inclusive, give the composition of the limestone in different parts of the quarry, and show that on the whole it is extremely pure and unusually low in silica, alumina, and iron, making it an exceptionally fine stone for manufacture into lime, and suitable also both for use in the blast furnace and for open-hearth flux. Moreover, its composition adapts it for use in the manufacture of Portland cement, which could be made here by combining it to form a mixture with the overlying slate and the nearby Triassic shale. A further description of the development of this property by the Tidewater Portland Cement Company is given on pages 370 to 377.

The *Haines Quarry* (No. 7) is opened, as has been stated on a previous page, on the same high-grade bed of limestone as the Wolfe Quarry. This quarry is owned by Wm. Haines, of Union Bridge. A 27-foot face is worked and, as at the Wolfe Quarry, the stone dips about 20° towards the east. The overburden on the east is heavy, and as a result most of the rock is taken from the west end of the quarry, where the residual soil is not so thick nor so expensive to remove. Three stone kilns of the continuous mixed-feed type, are located on the west side of the quarry in which practically all the stone that is quarried is burned into lime.

About $1\frac{3}{4}$ miles southwest of Union Bridge, on the *Rhinehart property*, a quarry has been opened within the past two years for purposes of quarrying marble. The crystalline limestone is here characterized by a faint creamish tint, is fine-grained, and takes a beautiful polish. The quarry is located on the map between the numbers 8-13, which also denote the numbers given the samples which were taken for chemical analyses.

This crystalline limestone or marble has a workable thickness of a little over 220 feet. As at present developed by the Maryland Cremo Marble Company, the only marble operator in the western Piedmont, the width of the quarry is about 60 feet. The marble is quarried by means of Sullivan channelers, which are here used to cut or channel the stone at right angles to the strike. The strike here is N. 15° E., and the dip 50° east.

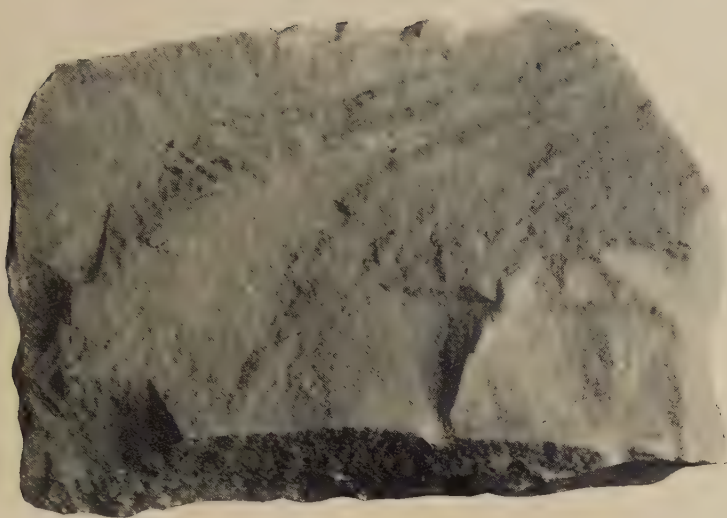


FIG. 1.—CRYSTALLINE LIMESTONE, FINE-GRAINED AND CREAMY WHITE, TIDEWATER PORTLAND CEMENT COMPANY QUARRY, UNION BRIDGE.



FIG. 2.—ARGILLACEOUS OR SHALY LIMESTONE, FOLDING BROUGHT OUT BY WEATHERING, CLEAR RIDGE.

TYPICAL LIMESTONES OF WESTERN PIEDMONT.

The accompanying Plate XIV, Fig. 2, gives a very correct idea of the amount and manner of the development at the time the photograph was taken, during the summer of 1907. As shown in the photograph this marble appears to be absolutely white. As a matter of fact, instead of being a hard and dead, lusterless white it has a beautiful cream tone. As a building and decorative stone it is one of the most attractive and pleasing the writers have seen in Maryland.

ARGILLACEOUS MATERIAL.—Among the sources of nearby argillaceous material available for mixture with the crystalline limestones of Carroll and Frederick counties are the red and gray shales of the Newark formation and the slaty volcanics.

Judging from their color these appear much higher in iron than is really the case, as will be shown by the following analyses, one of which was made on a sample of the sandstone and the other on a sample of the shale:

ANALYSES OF TRIASSIC SANDSTONE AND SHALE, ROCKY RIDGE, MD.

	I Sandstone.	II Shale.
Silica (SiO_2)	70.01	64.19
Alumina (Al_2O_3)	12.48	16.25
Iron oxide (Fe_2O_3)	4.62	5.61
Lime (CaO)	2.78	1.80
Magnesia (MgO)	1.30	2.42
Ignition	3.99	4.55
Undetermined	4.82	5.18
Total	100.00	100.00

I. Just east of Rocky Ridge. Anal. Zies and Schmidt.

II. 2 miles east of Rocky Ridge. Anal. Zies and Schmidt.

As can be seen from the above analyses the shale, though high in iron, would nevertheless be suitable to use in the manufacture of Portland cement. These shales outcrop on the Western Maryland Railroad just west of Union Bridge and might be used to advantage with the high-grade limestones that occur there, the two furnishing a mixture that should burn to an excellent cement. Less ferruginous shales occur nearby and could be added to the mixture if it should be necessary.

The slaty volcanics which usually flank the limestone valleys in the western Piedmont vary in composition, but are at times suitable for use

in Portland cement manufacture. The composition of two of these from the vicinity of Union Bridge are as follows:

ANALYSES OF SLATY VOLCANICS, UNION BRIDGE.

	I.	II.
Silica (SiO_2)	45.80	45.73
Alumina (Al_2O_3)	19.06	15.85
Iron oxide (Fe_2O_3)	11.73	26.91
Manganese (MnO)	.10	.04
Lime (CaO)	1.15	1.77
Magnesia (MgO)	11.71	2.78
Alkalies ($\text{Na}_2\text{O} + \text{K}_2\text{O}$)	3.86	2.84
Ignition	8.02	4.18
Total	101.43	100.10

I. Altered volcanic, $\frac{1}{4}$ mile E. Union Bridge. Anal. Zies and Schmidt.

II. Purple volcanic, Little Pipe Creek $\frac{1}{2}$ mile N. Union Bridge. Anal. Schmidt.

*The Tidewater Portland Cement Company.**

Property and Materials.—The property consists of 181 acres, of which at least 50 per cent. is composed of limestone and shale. The limestone used varies in composition from 95 to 99.5 per cent. of carbonate of lime and from a trace to 4 per cent. carbonate of magnesia. The shale which directly adjoins the limestone, and which can be secured, if desired, from a common quarry, is also of excellent quality. Analyses of the raw materials follow:

ANALYSES OF LIMESTONE, WOLFE QUARRY, UNION BRIDGE.

Silica (SiO_2).	Oxides of alumina and iron ($\text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$).	Lime (CaO).	Magnesia (MgO).	Ignition.	Totals.	Carbonate of lime.
4.46	0.52	51.94	1.10	42.03	100.05	92.75
1.40	0.24	53.75	1.06	43.41	99.86	95.98
6.40	0.62	51.04	.65	40.84	99.54	91.14
1.72	0.56	53.45	1.08	43.19	100.00	95.45
0.28	0.24	54.45	1.34	44.27	100.58	97.23
1.26	0.36	54.35	.64	43.41	100.02	97.05
1.08	0.20	54.89	.46	43.63	100.26	98.01

ANALYSES OF SHALE.

Silica (SiO_2).	Alumina (Al_2O_3).	Iron oxide (Fe_2O_3).	Lime (CaO).	Magnesia (MgO).
58.00	22.28	8.40	0.42	2.06
52.74	23.44	11.30	0.20	2.33
54.54	24.24	9.80	0.85	1.78

* Data furnished by R. K. Meade.

The indications are that there is upon the various properties a practically inexhaustible supply of limestone. The shale deposits are very extensive, and the quantity of this available is sufficient to more than outlast the limestone deposits. This quarry is also discussed on page 367.

Quality of the Cement.—In order to determine definitely the suitability of the materials for the manufacture of Portland cement, they were mixed in the proper proportions, ground, burned and again ground, and the properties of the resulting product examined, just as would be done in the manufacture of Portland cement on a large scale. The cement so made was found to be equal to the best American Portland cements now on the market. The analysis and tests are given below:

CHEMICAL ANALYSIS OF CLINKER.

Silica (SiO_2)	19.94
Alumina (Al_2O_3)	7.57
Iron oxide (Fe_2O_3)	3.45
Lime (CaO)	65.58
Magnesia (MgO)	1.69
Sulphur trioxide (SO_3)	0.26
Loss on ignition.....	0.62

PHYSICAL PROPERTIES OF THE CEMENT.

Fineness: (Standard sieves and method of sieving.)

Residue on the No. 100.....	95.2
Residue on the No. 200.....	80.1

Setting Time: (Gilmore's needles.) Air and water 72° F.

Initial set.....	1 hour and 45 minutes.
Final set.....	4 hours and 45 minutes.

Constancy of Volume: (Soundness.)

Five-hour steam test, Pats remained firm and hard and showed no signs of distortion, checking, cracking or disintegrating.

Six-hour boiling test, Pats remained firm and hard and showed no signs of distortion, checking, cracking or disintegrating.

Tensile Strength:

Time in air.....24 hrs.	24 hrs.	24 hrs.	24 hrs.	24 hrs.
Time in water...	6 days	6 days	27 days	27 days
Total age .....24 hrs.	7 days	7 days	28 days	28 days
Composition .....Neat	Neat	*Sand	Neat	*Sand
Strength .....350	810	275	1025	410
In pounds ....380	825	260	1000	425
Per sq. inch....375	845	255	1005	415
Average .....372	827	263	1010	417

* One part cement to three parts standard Ottawa sand.

White Portland Cement.—The limestone is unusually free from iron, and hence may be used for the manufacture of white Portland cement. Deposits of limestone sufficiently pure to be used for this purpose are very rare, and this is one of the few deposits in the country suitable for this purpose. A sample of white Portland cement made from this limestone had the following composition and properties:

CHEMICAL ANALYSIS OF WHITE CLINKER.

Silica (SiO_2)	22.12
Alumina (Al_2O_3)	7.56
Iron oxide (Fe_2O_3)	0.28
Lime (CaO)	64.10
Magnesia (MgO)	1.03
Sulphur trioxide (SO_3)	0.21
Loss on ignition	0.74

PHYSICAL PROPERTIES OF THE WHITE CEMENT.

Fineness: (Standard sieves and method of sieving.)

Residue on No. 100.....	94.8
Residue on No. 200.....	81.2

Setting Time: (Gilmore's needles.) Air and water 72° F.

Initial set.....	1 hour and 30 minutes.
Final set.....	5 hours.

Constancy of Volume: (Soundness.)

Five-hour steam test, Pats remained firm and hard and showed no signs of distortion, checking, cracking or disintegrating.

Six-hour boiling test, Pats remained firm and hard and showed no signs of distortion, checking, cracking or disintegrating.

Tensile Strength:

Time in air.....	24 hrs.	24 hrs.	24 hrs.
Time in water.....		6 days	6 days
Total age	24 hrs.	7 days	7 days
Composition	Neat	Neat	*Sand
Strength	245	650	225
In pounds	200	645	240
Per sq. inch.....	215	670	220
Average	220	655	228

* One part cement to three parts standard Ottawa sand.

These tests show the white Portland cement made from this limestone to be the equivalent not only of any white Portland cement now on the market, but also to be the equal in strength of the best brands of Portland cement.

DESCRIPTION OF PLANT.—The two raw materials lie directly to the south of the plant, a small creek separating their quarries from the mill site. The location can hardly be improved upon, both raw materials lying as they do, adjacent to the mill site, and there being sufficient water in the creek at all seasons of the year to supply the needs of the plant.

The plant will consist of a mill of 2400 barrels' daily capacity for the manufacture of Portland cement, a mill with a capacity of 600 barrels

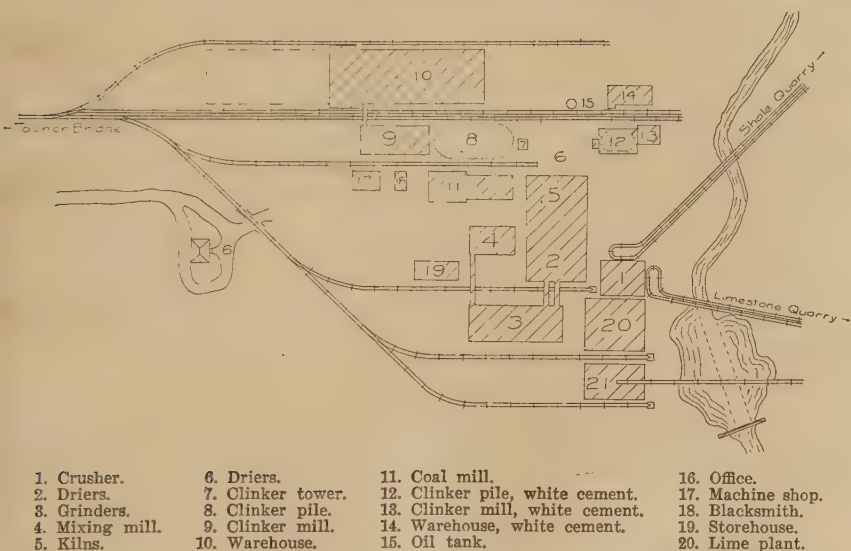


Fig. 21.—Plan of arrangement of buildings, Tidewater Portland Cement Company, Union Bridge.

for white Portland cement, and a lime plant with a capacity of about 60 tons of lime and hydrated lime.

The limestone and shale, after quarrying, will be conveyed in steel cars to the crushing house. In this will be located one No. 9, and three No. 6½ Gyratory crushers, all being driven by large motors. The cars will be drawn to the plant by means of an electric cable and will discharge directly into the No. 9 crusher, which will reduce the material to pieces about six inches in diameter. From this crusher the material will pass into a large elevator which will distribute the material into the three

smaller crushers, where it will be crushed so that all the product will pass through a $2\frac{1}{2}$ -inch ring. From the crusher part of the material will be carried into storage for the night run and part will go directly to the driers. The storage will have a capacity of about 1500 tons in order to prevent shut-downs due to rainy weather and similar causes.

The shale will be brought in by means of cars which will be loaded by a steam shovel at the shale bed. These cars are to be hauled to the mill by an electric tramway and the shale there crushed in a No. 6 $\frac{1}{2}$ crusher, from which it will pass to the storage and driers. There will be three driers, seven feet in diameter and 50 feet long, two of which will be used for limestone and one for shale. These driers are to be located directly back of the kilns in order to utilize the waste heat from the kilns for drying the stone, thus saving coal. Leaving the driers, the material, still separated, will be carried to Krupp ball mills, of which there are to be three, two for limestone and one for shale. These ball mills granulate the material. From them the shale and limestone will be passed to storage bins, which will have a capacity of 5000 tons of raw material; 3000 tons of limestone and 2000 tons of shale.

The material will be drawn from the storage bins in proper proportions as determined by analysis and mixed by automatic mixing machines. After this, it will be finely pulverized by a battery of nine Fuller mills, which are considered to be the most improved machines at the present time available for pulverizing.

Leaving the Fuller mills, the material will be carried to the five kilns, four of which will operate on Portland cement and the fifth on white Portland cement. The material fed into the kilns by means of a screw conveyor will discharge directly into an inclined feed-pipe leading into each kiln. The kilns will operate with the Matcham natural draft system of coal-burning.

Leaving the kilns, the clinker will be lifted into the coolers, one of which will be provided for each kiln. These will be 6 x 60 feet, and the clinker will be cooled by a current of air drawn through them by a stack. On leaving the coolers, the clinker will be conveyed to a clinker storage. This latter will consist of an overhead conveyor arranged to deposit the

clinker in piles, where it will be exposed to the atmosphere and allowed to season and soften. Underneath the clinker piles are to be tunnels in which operate belt conveyors.

From the storage the clinker will be carried to the finishing mill. Here it will be first crushed by means of ball mills, and then ground in fourteen Fuller mills. Before being ground the clinker will be mixed with the proper percentage of gypsum. The Fuller mills will grind a much finer cement than can be produced with other types of grinding machinery, and it is expected that the product of the Tidewater Portland Cement Company's plant will be ground so fine that 85 per cent. of it will pass a No. 200 mesh sieve, thereby yielding 10 per cent. more cementing materials in a barrel of Tidewater cement than is present in ordinary cements, only 75 per cent. of which will pass a No. 200 mesh sieve.

After being ground the material will be passed to the stock house, where it will be stored and seasoned ready for shipment. At one end of the stock house will be the bagging house and loading platform. The cement will be bagged by means of Bates valve bag machines, which automatically bag and weigh the cement.

The coal for burning will be brought in on cars from the mines in West Virginia and dumped into a hopper below the tracks. From this it will be carried up to the coal storage by means of an elevator. From the storage it will be drawn by gravity to a set of rolls which will crush the larger lumps. It will then pass into the coal driers, which will be of the Meade type. After being dried the coal will be pulverized in Fuller mills and carried over to the kilns. The plant will be electrically driven throughout.

There will be three large cross-compound engines, directly connected to a large alternating generator. There will also be in this department one relay unit for break-down devices, a motor generator and an engine-driven generator for exciting the generators. There will also be a switch-board.

In the boiler house there will be six 404-H. P. water-tube boilers. These boilers will be fired by means of Lehigh stokers. The cars will be brought in alongside the power house on a trestle and dumped into a

hopper. From this hopper the coal will be lifted by means of an elevator to the top of the boiler house and discharged to a long continuous bin above the stokers. There will also be the usual boiler feed-pumps, condensers, etc.

In connection with the cement plant there will be a fully equipped machine-shop for repairing any machinery of the type used in the plant.

The buildings will all be constructed of steel with expanded metal and concrete siding. The roofs of all buildings, except the boiler house and kiln building, which will be of corrugated iron, will be of matched flooring covered with composition roofing.

Each grinding unit will have its own bin, which in most cases will be sufficient for from 12 to 24 hours' run. The kilns will be provided with large individual bins, each of which will hold sufficient material for 24 hours' run. All the conveying will be done by means of bucket-chain elevators, and either screw or belt conveyors. The installation throughout will be such as to save labor and fuel.

The machines for grinding the raw material from which the white Portland cement is to be manufactured will be located in the same room as that used for grinding the ordinary Portland cement. The mills used for grinding the white Portland cement clinker will be in a separate building and the stock house for the white Portland cement will be separated from the stock house for the gray Portland cement. Oil will be used for burning the white Portland cement, and a large tank for storing this will be situated some distance to one side of the plant, on the hill. The oil will be delivered to this tank by means of tank cars.

The lime plant now built consists of five Keystone kilns. The stone is carried to the top of these by means of a runway and side-dump cars. The firing floor is provided with tracks and cars for distributing the coal in front of the various furnaces. The coal is brought in alongside the building and dumped into a hopper. From this it is carried up and dumped into the cars by means of an elevator. Below the firing floor is situated the cooling floor. The lime is taken from the kilns and spread upon this to cool. When it is desired to hydrate the lime, this is first passed through a Sturtevant Open-Door Crusher. From this it goes to



FIG. 1.—“HONEYCOMB ROCK,” AMYGDALOIDAL CATOCTIN SCHIST OR BASIC VOLCANIC ROCK,
WESTMINSTER.

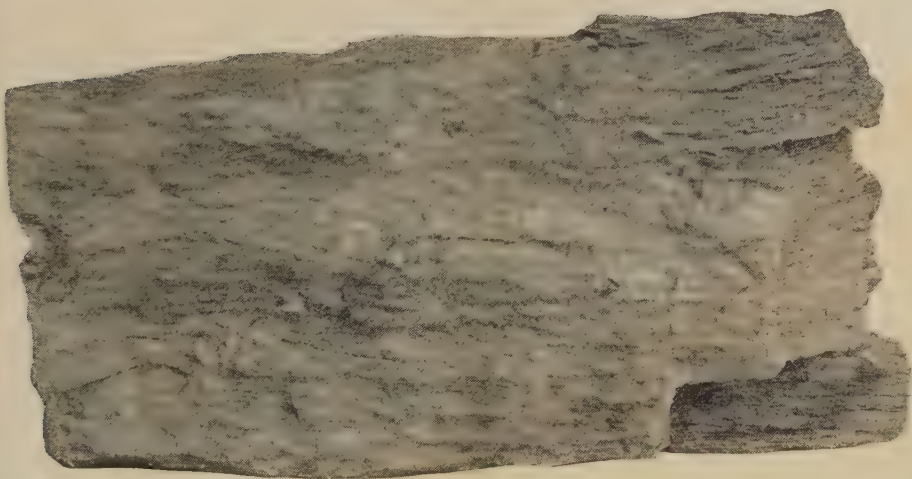


FIG. 2.—SLATY METARHYOLITE, OR ACID VOLCANIC ROCK, WITH FELDSPAR PHENOCRYSTS,
SAM'S CREEK.

TYPICAL VOLCANIC ROCKS OF WESTERN PIEDMONT.

a hydrating machine of the Kritzer make, where it is mixed with water. After being hydrated, the unhydrated material is separated by means of two Newaygo screens. The tailings are sent to the cement mill and used in place of limestone for cement manufacture. The product of the screens is delivered into two large bins above the bagging machines. These are of the Bates valve bag type. The lime plant is driven by its own engine and boiler.

Location.—The plant of the Tidewater Portland Cement Company is situated on the Western Maryland Railroad only 45 miles from tide, and thus is admirably located to distribute its products at low cost, not only to Baltimore and Washington but by water transportation over a wide district along the Atlantic Coast. No cement works yet constructed in this country are more favorably located for this purpose than the plant of the Tidewater Portland Cement Company.

Summary and Statistics for the Western Piedmont.

The best grade of limestone in the western Piedmont near transportation facilities is located in the vicinity of Union Bridge where it can be and is quarried at a lower cost, probably, than at any one of the competing points along the Western Maryland Railroad in the Piedmont. At Linwood and New Windsor the limestones are either too high in magnesia or else the amount available is limited and costly to obtain. Both conditions usually prevail at each of these points. On the other hand, in the vicinity of Unionville, the stone is of little value either as to quality or quantity. It is used to supply, in part, a small local demand. Around Westminster where there is limestone, both of good and indifferent quality, white crystalline limestones occur, ranging from a low to high content of magnesia, and often other impurities in varying amounts. The heavy overburden of residual soil and volcanics encountered in all of the quarries near Westminster prohibits a very large development except at an excessive and unprofitable cost.

The total value of lime produced in the western Piedmont in 1908 amounted to over \$16,000, the largest single operator being at Union Bridge. The value of limestone produced and sold for ballast, build-

ANALYSES OF LIME AND CEMENT MATERIALS OF WESTERN PIEDMONT.
CARROLL COUNTY.
LIMESTONES.

Name of limestone.	Map No.	Quarry.	Nearest town.	Si- lica. (SiO ₂).	Alumina (Al ₂ O ₃).	Iron (Fe ₂ O ₃).	Lime (CaO).	Magnesia (MgO).	Ignition.	Total.	CaCO ₃ .	Analyst.
White.	1	Geo. W. Albaugh.	Springville.	3.34	1.44	.80	50.43	1.85	41.55	99.43	89.8	M. R. Schmidt.
"	2	"	"	8.06	3.80	1.63	47.84	1.43	37.74	100.05	84.3	M. R. Schmidt.
"	3	"	"	2.50	.61	.53	52.63	1.40	42.63	100.19	93.5	M. R. Schmidt.
"	4	Roop.	Spring Mills.	1.63	.82	.67	58.92	15.30	45.27	99.64	64.1	M. R. Schmidt.
"	5	B. F. Shriver.	"	1.81	.46	.46	42.81	10.19	45.65	99.42	76.3	M. R. Schmidt.
"	6	Wm. Carbaugh.	New Windsor.	1.03	.51	.52	41.27	11.73	45.55	100.10	73.7	Zies & Schmidt.
"	7	Roop-Zies.	"	2.63	.45	.51	53.53	1.92	43.49	100.13	95.1	Zies & Schmidt.
"	8	Haines.	Linwood.	2.63	.45	.51	50.19	4.28	43.12	100.60	89.6	Zies & Schmidt.
"	9	"	"	1.02	1.57	.35	40.51	11.74	43.72	98.91	72.4	E. G. Zies.
"	10	"	Uniontown.	16.25	4.81	1.68	40.46	2.95	33.69	99.84	72.3	M. R. Schmidt.
"	11	Geo. R. Staub.	New Windsor.	1.07	1.04	.33	42.87	10.54	44.93	100.83	76.5	M. R. Schmidt.
"	12	D. A. Smith.	"	4.94	2.64	.39	43.25	2.17	41.52	99.91	85.1	E. G. Zies.
"	13	"	Union Bridge.	23.61	5.73	1.41	35.04	3.49	30.04	99.32	82.5	M. R. Schmidt.
"	14	"	"	2.17	.39	.72	54.82	10	42.60	100.08	98.0	Zies & Schmidt.
"	15	"	"	1.87	.56	.88	34.16	16.27	46.26	98.84	62.7	M. R. Schmidt.
"	16	Clemson.	"	1.73	.84	.33	44.03	8.28	44.51	99.82	78.3	E. G. Zies.
"	17	"	"	1.45	.66	.66	50.36	1.06	43.63	97.16	89.7	M. R. Schmidt.
Sandstone.			Rocky Ridge.	70.01	12.43	4.62	2.73	1.30	3.99	95.13*	....	
Shale.			"	64.19	16.25	5.61	1.80	2.42	4.55	94.82*	....	
Altered volcanic.			Union Bridge.	45.30	19.06	11.73	1.15	11.71	8.02	101.43	....	Zies & Schmidt.
Purple volcanic.			"	45.73	15.85	26.91	1.77	2.73	4.18	100.06	....	M. R. Schmidt.

ARGILLACIOUS MATERIALS.

FREDERICK COUNTY.

LIMESTONES.

1	Tidewater P. C.	Union Bridge.	1.08		.20	54.89	.46	43.63	100.26	93.0	R. K. Meade.
2	"	"	3.90	2.02	.64	52.40	.72	41.86	101.54	93.43	H. P. West.
3	"	"	3.50	0.41	.09	52.59	.95	42.31	99.96†	93.5	Penniman & Browne.
4	"	"	1.39		.45	55.27	.35	43.02	100.48	98.7	Zies & Schmidt.
5	"	"	0.62	0.28	.02	54.89	.53	43.70	99.91†	98.4	Penniman & Browne.
6	"	"	4.32	1.86	.46	46.00	5.29	41.64	99.84†	81.9	Penniman & Browne.
7	Buffington.	Johnsville.	1.81	.78		53.88	6.29	42.62	100.06	96.0	E. G. Zies.
8	Rhinehart.	Union Bridge.	0.99	1.81	3.00	51.73	1.69	42.55	100.17†	92.0	Penniman & Browne.
9	"	"	0.49	0.04	0.05	54.12	1.32	43.98	100.04†	95.2	Penniman & Browne.
10	"	"	2.44	0.45	0.17	53.76	0.35	42.82	100.04†	95.9	Penniman & Browne.
11	"	"	5.02	0.46	0.13	51.12	1.49	41.88	100.20†	90.9	Penniman & Browne.
12	"	"	0.31	0.23	0.16	53.04	2.08	44.34	100.20†	94.4	Penniman & Browne.
13	"	"	3.51	0.83	0.18	47.53	4.73	42.87	100.15†	84.8	Penniman & Browne.
14	Norris.	"	3.77	1.03	.23	49.80	2.90	42.25	100.03	88.8	Zies & Schmidt.
15	Clemson.	Union Bridge.	1.42	.74		53.04	1.49	43.20	99.89	94.4	Zies & Schmidt.

ing, concrete, and road metal probably did not exceed \$3000, making the value of the lime and limestone produced in this section for 1908 aggregate approximately \$20,000. The list of operators located in the western Piedmont follows below:

WESTERN PIEDMONT.
CARROLL COUNTY.

OPERATOR.	ADDRESS.	QUARRY.
Carbaugh, Wm.	New Windsor	New Windsor.
Dutterer, John T.	Silver Run	Silver Run.
Everhart, Wm. H.	Westminster	Bachman's Mill.
Fritz, Mordecai	Uniontown	Uniontown.
Goodwin Lime Co.	Westminster	Westminster.
Haines, Wm.	Union Bridge	Union Bridge.
Leppo, Wm. A.	Silver Run	Silver Run.
Myers, John W.	New Windsor	New Windsor.
Shriver & Co., B. F.	Westminster	Westminster.
Wakefield Mill & Lime Co.	"	"
Wareheim, Denton S.	"	Cranberry.
Yingling, Wm. R.	"	Westminster.

FREDERICK COUNTY.

Crum, John D.	Walkersville	Daysville.
Kramer, D. K.	Mt. Pleasant	Mt. Pleasant.
Tidewater Portland Cement Co.	Union Bridge	Wolfe.*

* One mile south of Union Bridge.

FREDERICK VALLEY.

Frederick County is the leading lime-producing county in the State, and contains the raw materials upon which this industry is based more abundantly than any other county east of the Blue Ridge. Its limestones and shales also furnish the necessary material for the manufacture of Portland cement. The proximity of limestones and argillaceous materials in the Frederick Valley to two large markets, Baltimore and Washington, make this an especially attractive section for the building of Portland cement plants. Portland cement is a bulky product, and every mile saved in the matter of transportation adds just so much to the dividends of the company manufacturing it.

The limestones of the Shenandoah group or the "Valley limestones," as they are sometimes called, occur in Maryland on both sides of the Blue Ridge. They consist of gray, massive limestones of very great aggregate thickness, and on the east side of the Blue Ridge form the floor of the Frederick Valley, where they are extensively quarried and burned into lime. Most of the Shenandoah group of limestones are high in

magnesia, the bane of the cement manufacturer, but nevertheless there are many quarries and occurrences where the magnesia content is found to be quite low.

GEOGRAPHICAL LIMITS.

The Shenandoah limestones of the Frederick Valley, as may be observed from the accompanying map, cover a longitudinal-shaped area extending from Woodsboro on the north, where it emerges from beneath the Newark formation, to the Potomac River, about 7 miles south of Buckeystown. It attains its maximum areal width of about 6 miles in the vicinity of Frederick, and its least of about $\frac{3}{4}$ of a mile where it crosses the Potomac. On the west it passes under the Newark formation, except in one instance where the latter has been removed by erosion, when it is in faulted contact with the underlying Harpers shale, and on the east is in juxtaposition with altered volcanics and sedimentary shales and slates of undetermined age.

The northern portion of the Frederick Valley is known as Glade Valley, and is so called from the stream that flows south and drains this portion of it. Woodsboro station, on the Northern Central Railway, is situated at its northern end.

The city of Frederick occupies, approximately, the center of the valley, and is reached from the north by the Northern Central Railway and from the south by the Baltimore and Ohio Railroad, via Frederick Junction. A branch line runs from here into Frederick, while the alignment of the main track is eastward. At Frederick Junction the main line bridges the Monocacy, and within the limits of the Ijamsville quadrangle parallels the course of Bush Creek, crossing slates, altered volcanics, and other rocks of undetermined age and origin.

These two railroads furnish the transportation facilities for all the lime operators of this section, bringing them their fuel and carrying their finished product to market. Large quarries and batteries of kilns are in operation to the east of Frederick, located along and near the branch road leading to Frederick Junction. Plants for the manufacture of lime are in operation also in the Frederick Valley on the main line of the Baltimore and Ohio at and near Limekiln, Keller, and Buckeys-

town. There are no large quarries between Buckeystown and Daubs, where the limestone of the Frederick Valley becomes hidden on the west by overlying Triassic shale and sandstone. Between these two stations limestone of good quality undoubtedly occurs, but has never been extensively exploited, probably because of the thickness of the residual soil concealing the underlying limestone, which, but for this overburden, could be readily quarried and utilized. Broadly speaking, the amount and thickness of residual soil is less north of Frederick than it is either on the east or south, and the operators to the north of the city, on the line of the Northern Central Railway, near Walkersville and Woodsboro, are put to less expense in their operations for the removal of overburden and water.

At present there are no cement plants in the Frederick Valley, but, as may be seen from the table of analyses, suitable material occurs and may be found at points definitely known, while there are many others that remain to be located, and could be found also were further expense incurred to pay for the time and effort necessary to find them. This is in reference, of course, to the limestone. Shale, which occurs on all sides of the valley in abundance, and often of suitable character to mix with the limestone, might be located definitely likewise.

The juxtaposition of limestone and shale, low freight rates to the leading markets, and facilities for transporting fuel, all go to make the Frederick Valley one of the most attractive parts of Maryland for the location of Portland cement plants.

GEOLOGY.

The limestones of Frederick County are of three major types: The crystalline limestones and marbles of the western Piedmont, exposed in the eastern part of the county, which have been described already as extending from the northeastern limits of the county to the vicinity of New London and New Market; the Shenandoah or valley limestones in the central part of the county; and the insignificant intercalated calcareous conglomerates and limestones of the Newark formation. Of these the second is the most important.

The Shenandoah group of limestones of Frederick are a local representative of the widely extending limestone series forming the great valley of Virginia, the Hagerstown Valley, of Maryland, and the Cumberland Valley, of Pennsylvania. The detailed discussion of these formations in the description of Washington County supplements the following concise description more applicable to the Frederick Valley.

Of the seven limestone formations, aggregating over 10,000 feet in thickness, recognized in Washington County, only the upper two or three have been found in Frederick County, and of these only the uppermost—the Chambersburg—aggregating probably less than 600 feet has been mapped east of the Blue Ridge. The areal limits of this formation against the overlying Martinsburg shales and the underlying limestones of questionably Stones River and Beekmantown age have been shown on the map. The exposure of all these formations is further limited by the overlying much younger Newark “red beds” and the contiguous older shales and volcanics on the western and eastern borders of the valley. All of the beds between these limits are proven by their fossils to be of Ordovician age.

The Chambersburg formation consists of impure limestones, argillaceous limestone, and calcareous shales. The beds richer in lime lie beneath the shaly beds. The whole formation appears to be intermediate both in composition and stratigraphic position between the overlying Martinsburg shales and the underlying lime-rich Stones River and Beekmantown limestones. The chief economic value of the Chambersburg lies in its argillaceous character, and in certain beds which are naturally almost perfect Portland cement mixtures. Suitable material for cement manufacture appears to be abundant and accessible.

The underlying Stones River and Beekmantown formations are freer from argillaceous matter than the Chambersburg, but increasingly magnesian in character passing downward. The beds just beneath the Chambersburg are nearly pure limestone, and these are followed by equally pure but thinner beds alternating with harder ones richer in magnesium. The beds high in lime, when exposed at the surface, may be recognized by the white, smooth, rounded surfaces of the ledges and

the velvety texture and characteristic dove color of freshly fractured fragments. The fact that these purer limestones yield a deep red soil well-suited to the cedars which grow upon it, has given to them the local name of "cedar stone" in areas where this formation is well developed.

The eastern limit of the limestone has usually been placed at the base of the low ridge of shales forming the eastern boundary of the valley, but recent investigations have shown the presence of numerous narrow and poorly exposed areas of limestone in minor valleys lying east of the easily recognized ridge of Martinsburg shales. The poor exposures resulting from the heavy cover of "wash" from the hills on either side do not offer the proof that these isolated exposures are connected, but the topography, geological structure, and areal distribution of the region indicate the presence of a continuous band of limestones between the first ridge on the west bordering the eastern side of the valley, and the shales and volcanics on the east representing the western limits of the rocks characterizing the western Piedmont.

DISTRIBUTION OF LIME AND CEMENT MATERIALS IN FREDERICK VALLEY.

Calcareous Materials.

WOODSBORO DISTRICT.—Two large limestone quarries are situated about a mile north of Woodsboro, and are separated by the diabase dike that crosses the railroad south of Le Gore Station. The quarry on the east side of the railroad, indicated by Nos. 16-21, and nearer the station, is owned and operated by the Le Gore Lime Company, while the other (Nos. 22-24) is the property of S. W. Barrick & Sons.

Several varieties of limestone are exposed in the *Le Gore Quarry*, which range in color from blue to light gray, and in texture from semi-crystalline to very fine grained. Samples were taken of several of these beds, which differed in physical appearance, in order to determine by analysis if possible whether the color and texture were in any way diagnostic of the composition. It was discovered that the light-gray limestones were the purest, and were lower in magnesia the softer the color tone and the more satiny the luster of the fresh-fractured surface.

Below are listed four of the samples from the Le Gore Quarry, with a brief description of their color and fracture, together with the numbers referring both to the points where the samples were taken, as shown on the map, and to their analyses in the table, giving the composition of various samples of limestone and shale coming from Frederick County:

ANALYSES OF LIMESTONES, LE GORE QUARRY, LE GORE.

	No. 16.	No. 18.	No. 19.	No. 20.	No. 21.
Silica (SiO_2)	4.21	4.55	2.85	8.51	2.34
Alumina (Al_2O_3)	1.18	1.61	{ .44 .71 }	{ 2.77 .78 }	.92
Iron oxide (Fe_2O_3)					
Lime (CaO)	52.76	49.40	54.00	38.72	51.80
Magnesia (MgO)	.75	3.25	.49	6.45	2.43
Ignition	41.46	41.68	42.25	40.07	42.75
Total	100.36	100.49	100.74	97.30	100.24

No. 16. Dove to light gray limestone, irregular to conchoidal fracture, partially crystalline, medium fine grained and compact.

No. 18. Bulk sample representing 150 feet.

No. 19. Very light gray chalcedony like limestone. Conchoidal fracture, fine grained to amorphous.

No. 20. Blue-gray limestone. Rough irregular fracture, and dull and faint and brownish saccharoidal luster.

No. 21. Gray limestone, semiconchoidal fracture, compact but slightly crystalline.

All of these samples, with the exception of the blue-gray limestone, ran fairly low in magnesia, as will be seen from the analyses.

The breast of stone worked in the Le Gore Quarry ranges from 30 to 60 feet in height. The beds strike N. 20° E. and dip 70° E., and the quarry is worked westward, or in a direction opposite to the dip. A bulk sample, representing the 150 feet of stone nearest the railway, namely, that on the westernmost side of the quarry, and including the several varieties of limestones mentioned above, ran, on analysis, as indicated. The magnesia is slightly high in the analysis, but the limestones it represents could be used in the manufacture of Portland cement in conjunction with either the shales on the west side of the valley or with the Triassic shales encountered along the line of the railroad a short distance north of Le Gore.



FIG. 1.—KILNS AND QUARRY OF S. W. BARRICK & SONS, LE GORE.



FIG. 2.—QUARRY AND KILNS OF LE GORE COMBINATION LIME COMPANY, LE GORE.

VIEWS OF FREDERICK VALLEY QUARRIES.

Nearly all of the limestone taken from this large quarry is burned into lime in a battery of 17 stone-constructed kilns located between the quarry and the railroad. By selecting and working beds of different composition the owners find it possible to produce limes that range in their content of calcium oxide from 96 to 98 per cent., and of a quality that will meet the various demands of the consumers.

The *Barrick Quarry* is opened on the west side of the railroad and northwest from the Le Gore Quarry. The diabase dike, already mentioned, passes between the two. The quarry in a northwest and southeast direction is from 350 to 375 feet wide, and in the direction of the strike (N. 15° E.) 400 to 500 feet long.

The breast of stone in this quarry is from 20 to 30 feet high, and is, therefore, not so high as in the neighboring Le Gore Quarry, but it is worked somewhat more systematically since the working face is kept in better alignment. About 75 per cent. of the limestone exposed here is from blue to dove in color, while the rest is almost white to very light gray, together with a small proportion along the eastern limits of the quarry of blue to grayish limestone, mottled with patches yellowish to brown in color, the so-called "gray-back" limestone.

A bulk sample taken at right angles to the strike and representing 350 feet of the Barrick stone showed, on analysis, a composition closely analogous and suitable for the same purposes as that of the Le Gore Quarry. The analysis follows below:

ANALYSIS (No. 23) OF A BULK SAMPLE FROM S. W. BARRICK AND SONS' QUARRY.
LE GORE.

Silica (SiO_2)	4.63
Alumina (Al_2O_3)	} 1.13
Iron oxide (Fe_2O_3)	
Lime (CaO)	49.45
Magnesia (MgO)	3.01
Ignition	41.79
Total	100.01

The so-called "gray-back" limestone was found to contain 6.72 per cent. of magnesia and a small amount (0.63 per cent.) of carbonaceous

matter. The complete analysis (No. 24) will be found in the table of analyses.

The lime kilns which are of the stone-constructed mixed-feed continuous type are built on the east side of the quarry. One of the batteries is on the edge of the quarry and west of the railroad, and the other on the opposite side of the railroad. The former is equipped with a mechanical appliance whereby the lime may be drawn from the kilns and loaded directly from them into the cars.

The first quarry south of Woodsboro on the line of the Northern Central Railroad is located 250 yards or more northwest of *McAleer* Station, and is owned by Frank M. McAleer. The working face where the rock is somewhat fissured is low, averaging about 15 feet with a soil overburden ranging in different parts of the quarry from 5 to 15 feet in thickness. On fresh fracture the limestone quarried here is blue in color but weathers on the surface to a light gray. It is burned in a battery of three kilns located at the station and on the west side of the railroad. The beds dip 55° E. and strike N. 20° E. A sample (No. 25), including the working face and representing in all 100 feet in a southwesterly direction perpendicular to the strike, showed a rather high content of silica, but was low in magnesia.

WALKERSVILLE DISTRICT.—No quarries have been opened between McAleers and Woodsboro or between the former and Walkersville, about 2 miles south of McAleers, because between these points the limestone is generally covered by a heavy mantle of residual soil.

The only remaining important limestone quarry between Woodsboro and Frederick is at Fountain Rock, a little over a mile, along the Northern Central Railway, south of Walkersville. With the exception of faulting, which is here absent, the quarry shows clearly the general structure of the Shenandoah limestone throughout the Frederick Valley. As can be seen from the accompanying illustration the limestone of the *Fountain Rock Quarry* is folded first into a syncline at the eastern end of the quarry, which in the west is followed by the anticline shown on the left side of the picture.

The breast of stone at the east end of the quarry is 48 feet. The lower 28 feet of gray to dove-colored limestone was included in one sample (No. 31), while the upper bench of 20 feet of blue limestone was represented by a separate sample (No. 30).

ANALYSES OF LIMESTONE, FOUNTAIN ROCK QUARRY, FOUNTAIN ROCK.

	No. 30.	No. 31.
Silica (SiO_2)	6.65	3.62
Alumina (Al_2O_3)	1.30	.93
Iron oxide (Fe_2O_3)	.51	.30
Lime (CaO)	47.99	46.41
Magnesia (MgO)	3.09	5.82
Ignition	40.47	42.59
Total	100.01	99.67

The upper bench, as both the weathering in the field and the analyses made in the laboratory show, is higher in silica than the underlying beds. The analyses also bring out the further fact that the content of magnesia in the lower bench of stone is higher than that of the superjacent 20 feet. They average 4.5 per cent. of magnesia, which would make it difficult to manufacture the stone into a Portland cement that could meet the rigid requirements of the standard specifications unless some purer stone were introduced into the mixture. This could be obtained from the quarries near Woodsboro.

Some of the limestone from this Fountain Rock Quarry is sold for ballast and concrete work, but most of it is calcined and the product sold largely to farmers for liming their land. The burning, heretofore, has been carried on in the old-fashioned stone-constructed type of continuous kiln, but the Fountain Rock Lime Company, which owns both the quarry, formerly known as the Stimmell Quarry, and the kilns, is replacing the old battery with steel-clad, brick-lined kilns, not only more modern in design but better, producing, as they do, a higher-grade product and effecting also a considerable saving in the cost of fuel.

FREDERICK DISTRICT.—Three limestone quarries are situated near Frederick, one to the east of the town, and two to the southeast. All are at present in operation. The quarry at No. 34 is owned and operated by Gilmer Schley. Of the two southwest of Frederick, the larger

is operated by the M. J. Grove Lime Company, which also owns quarries at Limekiln, while the smaller quarry was owned until recently by the Frederick Lime and Stone Company. Both quarries on the south are on the south side of the Baltimore and Ohio Railroad, the former, the M. J. Grove Lime Company's quarry, being about $1\frac{1}{2}$ miles from the Baltimore and Ohio station in Frederick, and the latter, the Frederick Lime and Stone Company, approximately $\frac{3}{4}$ of a mile southwest of the same point.

An exposure of argillaceous, thin-bedded limestone occurs at a short distance east of the Baltimore and Ohio station in Frederick, which at one time was used either for ballast, as a road metal, or for burning into lime, as is evidenced by a small, abandoned quarry on the south side of the railroad about 200 yards beyond the station. A bulk sample taken perpendicular to the strike, or, in other words, at right angles to the direction of the dip, and representing every inch of a stratigraphic thickness of 82 feet showed, on analysis, the following composition:

ANALYSIS (No. 35) OF ARGILLACEOUS LIMESTONE, FREDERICK.

Silica (SiO_2)	9.65
Alumina (Al_2O_3)	2.18
Iron oxide (Fe_2O_3)	.90
Lime (CaO)	46.42
Magnesia (MgO)	3.04
Ignition	38.43

Total	100.62
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The composition and physical character of the limestone whose analysis is given above make it an exceedingly suitable material to use with a shale of low content of magnesia in the manufacture of Portland cement. Shale of this character occurs on the line of the Baltimore and Ohio Railroad just across the river from Frederick Junction. The strike of the limestone at the locality here mentioned is N. 25° E. with a dip of 25° E. Limestone of a similar character is exposed about midway between Frederick and Frederick Junction, and again between the midway point and the Junction itself.

The *Gilmer Schley Quarry*, as has been stated, is directly east of Frederick. On this property there are two quarries, the old one now

practically abandoned because of the heavy overburden and the necessity of pumping in order to keep the quarry free from water. It is located to the northeast of where Carroll Creek crosses the Frederick-New Market road. West of this point, and about 550 feet north of the road just mentioned, is the battery of four kilns in which is calcined most of the rock quarried from the new quarry opened at a distance of between $\frac{1}{4}$ and $\frac{1}{2}$ of a mile further down the stream, from which the stone is hauled in carts to the kilns.

The stone in the new Schley Quarry opened at the point on the map marked 34 ranges in color from light blue through dove to gray, and has a working face of from 25 to 30 feet. Compared with the old quarry the cover of residual soil in this new quarry, though from 3 to 6 feet in thickness, is small, inasmuch as that of the old quarry back and east of the kilns varies from 15 to more than 20 feet. The width of the quarry is about 60 feet. The chemical analysis of a bulk sample of the quarry shows it to be unusually high in magnesia, containing, as it does, over 17 per cent.

Passing from Frederick to Frederick Junction, on the Baltimore and Ohio Railroad, the quarry formerly owned by the Frederick Lime and Stone Company, and now the property of the *Tabler Lime and Stone Company*, is the first quarry on the west of the railroad just outside of Frederick, and 2000 feet north of the Grove Quarry, the next quarry to be described. The color of the stone is blue and weathers to a dove color. It dips 10° to 12° E., and the strike of the bed is N. 50° E. At the north end of the quarry, namely, the end nearest the railroad, the breast of stone is 32 feet. Differential weathering has occurred at both ends of the quarry, and particularly at the south end. At the north end it is shown by the more or less corrugated appearance of the stone, the softer and purer material occupying the furrows, while the harder and more siliceous forms small ridges parallel to the bedding.

The following is an analysis made for the Tabler Lime and Stone Company of sample of their lime submitted for analysis to Dr. Charles F. McKenna, 221 Pearl Street, New York, N. Y.:

ANALYSIS (No. 36) OF LIME FROM TABLER LIME AND STONE CO.'S QUARRY,
FREDERICK.

Silica (SiO_2)	2.09
Alumina (Al_2O_3)	.72
Iron oxide (Fe_2O_3)	
Lime (CaO)	91.48
Magnesia (MgO)	1.78
Ignition	4.11
Total	100.18

The same company supplied the writers with the following physical tests made on the limestone taken from their quarry:

CRUSHING TESTS ON LIMESTONE FROM THE TABLER LIME AND STONE CO.'S QUARRY
AT FREDERICK.

Ore piece. size.	Failed at pounds.
1" $\times$ 1" $\times$ $\frac{3}{8}$ "	17,000
1" $\times$ 1" $\times$ $1\frac{3}{8}$ "	29,950
1" $\times$ 1" $\times$ 1"	32,800
1" $\times$ 1" $\times$ 1"	32,140

The above tests were made by L. E. Kennedy, 11 Broadway, New York.

The stone occurring at the southern end of the Tabler Lime and Stone Company Quarry is covered with a heavy mantle of soil formed as the result of weathering and extending down between less soluble "horses" or masses of solid stone.

A sample taken of the 32-foot breast at the north end of the quarry gave, on analysis, the following:

ANALYSIS (No. 37) OF LIMESTONE, TABLER QUARRY, FREDERICK.

Silica (SiO_2)	8.17
Alumina (Al_2O_3)	2.69
Iron oxide (Fe_2O_3)	.48
Lime (CaO)	47.27
Magnesia (MgO)	2.34
Ignition	38.70
Total	99.65

In the above analysis

$$\frac{\text{SiO}_2}{\text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3} = 2.5$$

or, in other words, the ratio silica to alumina plus ferric oxide is about

correct. Moreover, the magnesia is low and other deleterious impurities are absent. A Portland cement mixture could, therefore, be formed by a combination of this limestone with the shale occurring on the line of the Baltimore and Ohio Railroad within $\frac{1}{2}$ mile east of Frederick Junction.

The M. J. Grove Lime Company's Quarry on the Baltimore and Ohio Railroad, between Frederick and Frederick Junction, is the largest quarry near Frederick. The cartographic position is shown on the map by the numerals 38-39. It is the second quarry met with going from Frederick to Frederick Junction, on the Baltimore and Ohio Railroad, or traveling along the Frederick-Baltimore turnpike, is the first quarry beyond the Tabler Quarry already described.

At the center of the quarry the limestone is folded into an arch or anticline, and is flanked on either side by synclines. The lower 20 feet of limestone at this point is dove-colored, and is surmounted by a darker limestone that is blue to light gray in color. The working face varies from 30 to 50 feet in different parts of the quarry, depending on the amount of overburden, which ranges from 10 to 20 feet. Samples were taken both on the east and south side of the quarry. The sample taken on the east side of the quarry, where the color of the limestone is blue and the stone is more or less crystalline, was obtained at the foot of the incline leading from the crusher down into the quarry. Its composition is given under No. 38, while the composition of the sample from the south end of the quarry will be found under No. 39.

ANALYSES OF LIMESTONE, M. J. GROVE'S QUARRY, FREDERICK.

	No. 38.	No. 39.
Silica (SiO_2)	23.86	2.47
Alumina (Al_2O_3)	.89	.77
Iron oxide (Fe_2O_3)	.53	
Lime (CaO)	36.65	43.64
Magnesia (MgO)	5.10	9.50
Ignition	33.46	43.97
Total	100.49	100.35

The latter represents the 80 feet of limestone on the west flank of the anticline mentioned as being exposed on the south side of the quarry.

Both these analyses show a content of magnesia too high to permit the limestone obtained in the Grove Quarry to be used in the manufacture of Portland cement, though it burns into a very good grade of lime. The company operates 17 kilns and has others of the steel-clad type in course of construction.

In order to get a suitable working face the owners of the Grove property have been obliged to deepen the quarry, and, as a result, have encountered water, necessitating the installation of pumping machinery to prevent the quarry being flooded. In the exploitation of this quarry, as in other limestone operations in the Frederick Valley, topography has helped very little in furnishing a natural working face to the quarry.

BUCKEYSTOWN DISTRICT.—The principal limestone quarries south of Frederick are situated at Limekiln and near Buckeystown. Those at the former place are on the west side of the Baltimore and Ohio Railroad, while those west of Buckeystown are opened up along the right-of-way, and are about $1\frac{3}{4}$ miles southwest, along the track, from Limekiln.

The quarries at Limekiln are owned and operated by the *M. J. Grove Lime Company*, which also owns, as previously mentioned, the large quarry and kilns between Frederick and Frederick Junction. The stone burned here in a battery of seven kilns is obtained from two separate quarries, neither very large, and both having a more or less heavy overburden of residual soil. The first and larger one of these quarries is a little more than $\frac{1}{4}$ of a mile east of the lime kilns and station, while the other is close to the track, and just west of the company's store. The smaller quarry near the station (Nos. 42-44) has a working face of about 30 feet at its southwest end. Because, however, of its depth, and especially for the reason that there is a heavy overburden which has to be removed on the quarry's east side, it has been practically abandoned in favor of the larger quarry first mentioned. The latter has a working face at the northeast end of the quarry of about 35 feet, while at the southern end the stone is much weathered and there is a heavy overburden of residual soil. In both these quarries the stone is blue to gray in color, and in the case of the stone from the larger quarry (analyses Nos. 40-41) is high in magnesia. There is less magnesia in the stone



FIG. 1.—STIMMEL QUARRY, FOUNTAIN ROCK LIME COMPANY, FOUNTAIN ROCK.



FIG. 2.—SOUTH END OF QUARRY, M. J. GROVE LIME COMPANY, FREDERICK.

VIEWS OF FREDERICK VALLEY QUARRIES.

in the quarry nearest the kilns (analyses Nos 42-44), but this advantage is counterbalanced by the extra cost of obtaining it.

ANALYSES OF LIMESTONE, M. J. GROVE'S QUARRIES, LIMEKILN.

	No. 40.	No. 41.	No. 42.	No. 43.	No. 44.
Silica (SiO_2)	0.85	3.76	3.90	0.31	3.53
Alumina (Al_2O_3)	0.72	{ 0.88 } { 0.50 }	0.36	0.14	{ 0.99 } { 0.12 }
Iron oxide (Fe_2O_3)					
Lime (CaO)	32.89	34.06	52.23	52.35	50.70
Magnesia (MgO)	18.60	15.82	1.30	2.84	3.13
Ignition	46.11	44.09	42.23	44.35	41.99
Total	99.17	99.11	100.02	99.99	100.56

There are a number of limestone quarries around Buckeystown, the largest and most important of which is the *O. J. Keller Lime Company's Quarry* situated east of the line of the Baltimore and Ohio Railroad $1\frac{3}{4}$ miles south of Limekiln. The limestone beds here range from blue to gray in color, and have been folded into an arch or anticline. Near the center of this arch, which has a span of about 300 feet, that being the length of the quarry in an east and west direction, the same pressure that produced the anticline has superinduced a synclinal flexure upon the major fold. The breast of stone varies in different parts of the quarry, but averages close to 30 feet. Samples from the southeast (No. 49), northwest (No. 48), and northern (No. 47) parts of the quarry showed, respectively, on analysis, the following contents of magnesia, 3.46 per cent., 2.83 per cent., and .66 per cent., or an average of 2.31 per cent. magnesia for the whole quarry. The complete analyses of these samples follow:

ANALYSES OF LIMESTONE, KELLAR QUARRY, BUCKEYSTOWN.

	No. 47.	No. 48.	No. 49.
Silica (SiO_2)	13.94	3.03	6.49
Alumina (Al_2O_3)	1.38 } .30 }	.95	{ .86 } { .47 }
Iron oxide (Fe_2O_3)			
Lime (CaO)	47.02	50.85	47.40
Magnesia (MgO)	.66	2.83	3.46
Ignition	36.73	41.81	41.17
Total	100.03	99.47	99.45

From these it is evident that the quality of stone makes it well adapted to manufacture into Portland cement, using the shale found on the Baltimore and Ohio just east of where the railroad after leaving Frederick Junction crosses the Monocacy River.

Argillaceous Material.

The manufacturer of Portland cement in the Frederick Valley may use either the Triassic shale on the west or the metamorphosed sedimentary and igneous slates occurring on the east. The Triassic shales are best situated for use near and north of Woodsboro on the line of the Northern Central Railway, though they also may be had on the Baltimore and Ohio Railroad at and southwest of Daubs Station, but the altered volcanics and metamorphosed sedimentaries are nearer to the operations around Frederick, and hence in starting a plant there a suitable shale deposit would be looked for along the line of the Baltimore and Ohio Railroad east of Frederick Junction.

Analyses of both varieties of shale mentioned above are given below. The analysis marked 8 was made on a sample of slate obtained 1860 feet east of the east bank of the Monocacy, where it is crossed by the Baltimore and Ohio Railroad bridge. The last 60 feet of this 1860 was represented in the sample, and the analysis shows that it fully meets all the requirements for use in the manufacture of Portland cement. The point where this sample was taken is indicated on map by the figure 8.

Samples of the Triassic shales were taken along the line of the Western Maryland Railroad at the points shown on the map as Nos. 1-5. Though they contain from 5 to 7 per cent. ferric oxide, nevertheless their content of iron is less than one would expect from their deep red color. They are low in magnesia and generally low in alumina, the latter being supplemented by ferric oxide. As 10 * per cent. is considered the upper limit of the amount of ferric oxide that a ferruginous shale may carry and still be used for Portland cement, it will be evident from

* Bull. III, Ohio Geol. Survey, p. 76.

what has been said above and from results given in the table of analyses, that certain of the Triassic shales would form a suitable cement material. The analyses of these shales are given below:

ANALYSES OF SHALE, FREDERICK COUNTY.

	No. 1.	No. 3.	No. 5.	No. 9.
Silica (SiO_2)	60.33	70.01	58.74	66.08
Alumina (Al_2O_3)	18.28	12.48	18.13	17.63
Iron oxide (Fe_2O_3)	7.12	4.62	6.15	4.62
Lime (CaO)	1.01	2.78	3.08	.37
Magnesia (MgO)	3.75	1.30	2.34	1.03

1. Partial Analysis, Shale. W. Md. Ry., Loys.
3. Partial Analysis, Shale. W. Md. Ry., Graceham.
5. Partial Analysis, Shale. W. Md. Ry., Graceham.
9. Partial Analysis, Shale. B. & O. R. R., E. Frederick Junct.

FREDERICK COUNTY.

ARGILLACEOUS MATERIALS.

Triassic. shale. (see Map No.	Quarry.	Nearest town.	Silica (SiO_2).	Alumina (Al_2O_3).	Iron (Fe_2O_3).	Lime (CaO).	Magnesia (MgO).	Alkalies.	Ignition.	Total.	Analyst.
1		Loys.	60.33	18.28	7.12	1.01	3.75	n.d.	4.18	94.67	Schmidt.
2		Graceham.	64.19	16.25	5.61	1.80	2.42	n.d.	4.55	94.82	Zies.
3		"	70.01	12.48	4.62	2.78	1.30	n.d.	3.99	95.18	Zies.
4		"	56.57	16.03	7.31	4.64	2.53	n.d.	7.30	94.48	Schmidt.
5		"	58.74	18.13	6.15	3.08	2.34	n.d.	6.21	94.95	Zies.
6		Johnsville.	47.85	16.04	20.19	0.60	6.07	3.94	5.07	89.76	Zies.
7	Tidewater P. C.	Union Bridge.	58.41	22.27	8.31	0.09	0.73	6.42	3.66	99.89	
8	Clemson.	"	n.d.	n.d.	n.d.	n.d.	n.d.	5.69	n.d.	....	
9		Frederick Junct.	66.08	17.63	4.62	.37	....	....	2.49	92.22	Zies.

SUMMARY AND STATISTICS FOR FREDERICK VALLEY.

The lime and limestone industry in the Frederick Valley is centered around the following five points, Woodsboro, Walkersville, Frederick, Buckeystown, and Limekiln, the last two on the Baltimore and Ohio Railroad south of Frederick, and the first two on the Northern Central Railway north of Frederick. Both of these railroads enter Frederick.

Frederick County, as usual, ranked first in the annual production of lime, the value of the product being in the neighborhood of \$200,000, while the value of the limestone sold for other purposes amounted to nearly \$50,000. The annual products resulting from the quarrying of limestone often reached or exceeded a total value of over \$300,000.

THE LIMESTONES OF MARYLAND

FREDERICK COUNTY.
LIMESTONES.

Name of limestone.	Map No.	Quarry.	Nearest town.	Silica (SiO ₂).	Alumina (Al ₂ O ₃).	Iron (FeO ₂).	lime (CaO).	Magnesia (MgO).	Ignition.	Total.	CaCO ₃ .	Analyst.
Chambersburg.	16*	LeGore.	LeGore.	4.21	1.18	1.18	52.76	.75	41.46	100.36	93.8	Zies & Schmidt.
"	17	"	"	4.50	.60	.40	55.10	.24	43.56	100.00	95.9	H. J. Patterson.
"	18	"	"	4.55	1.21	.40	49.40	3.25	41.68	100.49	87.9	Zies & Schmidt.
"	19	"	"	2.86	.44	.71	54.00	.49	42.25	100.74	96.0	M. R. Schmidt.
"	20	"	"	8.51	2.77	.78	38.72	6.45	40.07	97.30	69.0	F. G. Zies.
"	21	"	"	2.34	.92	.10	51.80	2.43	42.75	100.24	92.2	Zies & Schmidt.
"	22	Barriek.	"	2.53	10.10	.13	45.69	2.67	38.81	98.60	81.2	T. M. Price.
"	23	"	"	4.63	7.08	1.57	49.45	3.01	41.79	100.01	88.0	Zies & Schmidt.
"	24	McAleer.	McAleer Station.	11.30	33.97	6.72	37.55	6.72	37.55	98.19	60.6	Zies & Schmidt.
"	25	"	"	9.23	2.69	.35	45.74	2.24	38.17	99.42	83.2	E. G. Zies.
"	26	"	"	.50	...	...	55.72	...	42.98	99.20	95.7	"
"	27	"	"	0.89	.50	.50	54.88	.37	43.41	100.05	97.5	"
"	28	McAleer.	McAleer Station.	4.51	.90	.40	46.80	6.21	42.78	100.00	81.7	"
"	29	Stimmel.	Unionville.	4.51	.90	.40	46.80	6.21	42.78	100.00	81.7	"
"	30	"	Fountain Rock.	4.51	.90	.40	46.80	6.21	42.78	100.00	81.7	"
"	31	"	"	4.51	.90	.40	46.80	6.21	42.78	100.00	81.7	"
"	32	Tyson.	"	4.51	.90	.40	46.80	6.21	42.78	100.00	81.7	"
"	33	H. Cramer.	Mt. Pleasant.	8.92	1.30	.51	47.99	3.09	40.47	100.01	85.4	E. G. Zies.
"	34	Schley.	"	8.75	.85	.30	46.41	5.82	42.59	99.67	82.7	E. G. Zies.
"	35	"	"	9.98	8.74	.30	43.00	4.37	38.66	100.42	76.7	T. M. Price.
"	36	"	Frederick.	9.98	10.32	.61	43.99	0.99	35.65	100.61	78.3	T. M. Price.
"	37	Tabler.	"	9.45	.58	.61	34.02	17.11	46.41	99.71	60.6	E. G. Zies.
"	38	M. J. Grove.	"	2.18	.72	.90	46.42	3.04	38.43	100.62	82.7	Zies & Gill.
"	39	"	"	2.09	.72	.90	46.42	3.04	38.43	100.62	82.7	C. F. McKenna.
"	40	"	"	2.17	.69	.48	47.27	1.78	38.70	99.66	84.3	E. G. Zies.
"	41	"	"	2.36	.89	.53	38.66	6.10	33.45	100.49	64.8	E. G. Zies.
"	42	"	"	2.47	.77	.50	43.64	9.50	43.97	100.35	77.7	E. G. Zies.
"	43	"	"	0.55	.88	.50	32.89	1.86	43.30	99.62	58.8	"
"	44	"	"	3.76	.86	.50	34.06	15.82	44.09	99.11	60.8	E. G. Zies.
"	45	"	"	3.90	.86	.50	32.23	1.30	42.23	100.02	92.7	H. J. Patterson.
"	46	"	"	3.83	.99	.12	32.85	2.84	44.35	99.99	93.9	H. J. Patterson.
"	47	"	"	0.17	.26	.30	50.70	3.13	42.09	100.58	90.2	E. G. Zies.
"	48	Rogers.	Buckeystown.	4.99	6.33	.30	43.54	0.33	43.54	99.28	97.7	T. M. Price.
"	49	Keler.	"	13.94	1.38	.95	47.12	1.90	39.09	99.38	83.8	E. G. Zies.
"	50	"	"	6.03	1.38	.95	47.02	1.66	36.73	100.03	83.2	E. G. Zies.
"	51	"	"	6.49	.86	.47	47.40	3.46	40.77	99.45	84.4	E. G. Zies.

* Nos. 1 to 15 refer to analyses of limestones from the Western Piedmont portion of Frederick County, which may be found at the close of the discussion of the Western Piedmont, page 378.

† Burnt lime.

The following table gives the list of limestone operators and producers of lime in this section of the State. It includes the names, not only of the leading operators, but those of a goodly number who only work their quarries intermittently and burn lime occasionally:

LIME AND LIMESTONE OPERATORS IN FREDERICK COUNTY.

FREDERICK AND GLADE VALLEYS.

OPERATOR.	OFFICE.	QUARRY.
Barrick, S. W. & Son.....	Woodsboro	Woodsboro.
Brookey, Peter	Frederick	Frederick.
Cramer, David	Walkersville	Walkersville.
Crum, John D.....	"	Daysville.
Devilbiss, David A.....	"	Walkersville.
Eichelberger, Jacob	Woodsboro	Woodsboro.
Fountain Rock Lime Co.....	Frederick	Fountain Rock.
(J. W. Stimmel)		
Frederick Lime and Stone Co.....	"	Frederick.
Grove Lime Co., M. J.....	Limekiln	Limekiln and Frederick.
Isanogle, A. M.....	Thurmont	Catoctin.
Jones, Mordecai	Mt. Pleasant	New London.
Le Gore Lime Co.....	Le Gore	Le Gore.
Lewes, R. Rush.....	Frederick	Frederick.
McAleer, M. Frank.....	Walkersville	McAleer.
Roddy, F. Daniel.....	Mt. St. Marys.....	Motters.
Schley, Gilmer	Frederick	Frederick.
Shinham, D. M.....	Hagerstown	Fair View.
Zentz, David G.....	Thurmont	Thurmont.
Zimmerman, Wm. C.....	Walkersville	Walkersville.

WASHINGTON COUNTY.

Washington County is more generously supplied with raw materials suitable for the manufacture of limes and cements than any other county in the State. It is crossed from northeast to southwest by several belts of limestone, the broadest and most important lying in the eastern section of the county and forming for the most part the floor of the Hagerstown Valley, while the smaller form several detached areas within the Allegheny ranges.

The Hagerstown Valley is underlain by two limestone belts, with an intervening belt of shales. The broader of these belts, covering an area about 15 miles in width, occupies the area between the foot of the Blue Ridge on the east and the Martinsburg shale belt just west of Williamsport on the west. The narrower, covering a territory of from 4 to 5 miles in width, extends from the western margin of the Martinsburg shale belt, above mentioned, on the east, to the foot of North Mountain on the west.

The intervening shale belt has a width of from 2 to $2\frac{1}{2}$ miles. The limestones are admirably adapted to the manufacture of limes and cements, while the shales are excellent as an admixture for the latter. They are of Cambrian and Ordovician age.

In the western part of the county, west of North Mountain, the materials suitable for making lime and cement are less abundant and consist of narrow belts extending across the State. The age of the limestones of this section is Silurian and Lower Devonian, while most of the shales were deposited during the Middle or Upper Devonian.

HAGERSTOWN VALLEY.

The limestones forming the floor of the Hagerstown Valley occupy also the Cumberland Valley to the northeast in Pennsylvania, and the Shenandoah Valley to the southwest in Virginia. All three are but minor divisions of the one great valley that extends from New Jersey southward through Pennsylvania, Maryland, West Virginia, and Virginia, and finally ends in Alabama. These valleys mentioned above are distinguished mainly on the basis of the differences in the direction of their drainage. The waters of the Hagerstown Valley flow southward and empty into the Potomac, while the drainage of the Shenandoah Valley is in the opposite direction into the same river. On the other hand, the Hagerstown Valley is separated from the Cumberland Valley on the northwest by a watershed north of which the streams enter the Susquehanna, and south of which they flow into the Potomac.

Geology.

The Shenandoah limestones of the Hagerstown Valley are in contact on the west with the overlying Martinsburg shale, and on the east with the Harpers shale, since the Antietam sandstone, which normally lies between the limestone and Harpers shale, has been faulted out.

These limestones, composing the Shenandoah group, are blue to light gray in color, and range in composition from almost pure calcium carbonate to calcium carbonate more or less combined with magnesia, silica, alumina, iron, and other impurities. Where the last three are present

in considerable quantity the limestone becomes shaly or argillaceous. The amount of magnesia is rarely sufficient to form a true dolomite, but yet enough is present to make many of the beds valueless for Portland cement manufacture. The limestones also vary in texture from fine-grained to semi-crystalline, and have been found in certain areas of the eastern part of Washington County even as a pure, fine-grained marble.

The recent work of Geo. W. Stose, of the U. S. Geological Survey, has shown that the Shenandoah limestone may be divided into seven independent stratigraphic units. The total thickness of the Shenandoah group, according to his investigations, is about 10,000 feet, or nearly 2 miles.

The following table adapted from Stose* gives the divisions of the Shenandoah group, the overlying Martinsburg formation, and the two formations occurring immediately under the Tomstown, the lowest member of the Shenandoah group. It also gives a correlation with the standard New York section, and although this table refers particularly to the formation comprising the Shenandoah group in southern Pennsylvania, nevertheless it may be used to advantage for our present purposes since, with the possible exception of differences in thickness, it applies to the same divisions as they occur in Maryland:

GEOLOGICAL FORMATIONS OF HAGERSTOWN VALLEY.

Shenandoah group	Martinsburg formation.....	Eden.....	} Ordovician.
		Utica.....	
		Upper Trenton..	
		Lower Trenton..	
		Black River....	
	Chambersburg limestone 100-600 feet.....	Lowville.....	
	Stones River limestone 800-1000 feet.....	Upper Chazy....	
		Lower and middle Chazy	
	Beekmantown limestone 2250-2300 feet....	Beekmantown...	
	Conococheague limestone 1635 $\pm$ feet.....	Saratoga.....	
	Elbrook formation 3000 $\pm$ feet.....	Acadian.....	
	Waynesboro formation 1250 $\pm$ feet.....	Georgian.....	} Cambrian.
	Tomstown limestone 1000 $\pm$ feet.....		
	Antietam sandstone.....		
	Harpers shale.....		

* Journal of Geology, Vol. XVI, p. 698, 1908.

LIMESTONE FORMATIONS.—Four of the following formations are assigned to the Cambrian and three to the Ordovician, as will be seen by reference to the foregoing table. The thickness and physical characteristics peculiar to each are given below.

The Tomstown (Shady-Sherwood) Formation.—This is a massive drab to white magnesian limestone. Except near the base which is usually concealed the beds comprising this formation are generally impure and high in magnesia. The beds become cherty near the top and pass into alternating beds of sandstone and purple shale. The cherty portion is more resistant to weathering than the rest of the formation, with the result that the major part of the Tomstown formation, as a rule, occupies a valley parallel to the older siliceous rocks on the east

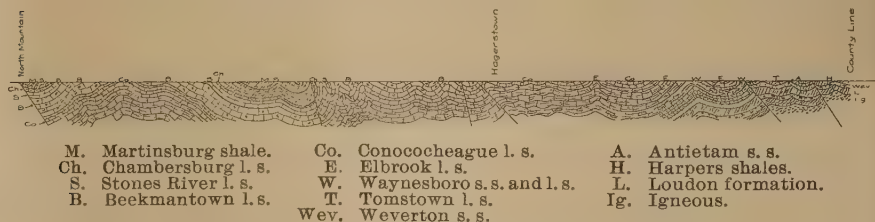


FIG. 22.—Section showing geological structure across Hagerstown Valley (through Hagerstown).

and the cherty ridge composed of the cherty portion of the Tomstown just mentioned. A more prominent ridge, sustained by the siliceous Waynesboro formation, rises, however, near the contact with the Tomstown a little farther west. The latter lies between the Antietam sandstone below and the Waynesboro (Wantaga-Buena Vista) shale above, and has a thickness of about 1000 feet.

The only occurrence of the Tomstown formation in Maryland is confined to the eastern part of Washington County, which it traverses in a general northeast-southwesterly direction. Entering the State from Pennsylvania immediately east of the Waynesboro Branch of the Western Maryland Railroad, it crosses the main line between the stations of Smithsburg and Cavetown, following the foot of the western slope of South Mountain. The area occupied is about $1\frac{1}{2}$ miles wide. The eastern limit of the formation follows the foot of the mountain, while



FIG. 1.—QUARRY OF S. P. ANGLE, HAGERSTOWN.



FIG. 2.—QUARRY OF POTOMAC VALLEY STONE AND LIME COMPANY, PINESBURG.

• VIEWS OF HAGERSTOWN VALLEY QUARRIES.

its contact with the overlying Waynesboro follows a line from Cavetown southwestward past Mt. Pleasant to the Washington County Branch of the Baltimore and Ohio Railroad, a short distance west of Keedysville. A roughly parallel line passing a short distance west of Boonesboro and Smithburg describes the boundary on the east. East of a line from Smoketown to Eakles Mills there is infolded a narrow belt of the more resistant ridge-forming Waynesboro. The southern limits of the Tomstown formation are marked by faulting and folding which divides the areal distribution into two narrow areas, one ending south of Eakles Mills, the other faulted a mile more or less north of Tregore Station.

This formation also extends southward to the Potomac near Harpers Ferry, as a small area which has been shifted westward by faulting.

The two chief industrial developments within the limits of the Tomstown formation are widely separated and distinctly different. That at Cavetown is on the Western Maryland Railroad. Here, P. G. Zouck and Company operate a quarry for the manufacture of crushed stone for ballast and for burning to lime. The other operation is at Eakles Mills and is conducted for the quarrying of marble. The white crystalline limestone or marble won here is the result of metamorphism caused by the proximity to and also presence of intense folding and faulting.

The Waynesboro Formation.—The Waynesboro formation, consisting largely of sandstones, purple shales, and hard limestones, yields little or no material for the manufacture of lime and cement, but is serviceable as a maker indicating by its long, low ridges and knobs the areal distribution of the underlying Tomstown and overlying Elbrook formations which form well-defined areas of depression on either side of the Waynesboro elevations.

The formation in Maryland occurs as three narrow belts extending parallel to the mountains in areas more or less enclosed by the adjoining formations. The first of these belts entering the State from the north extends southwesterly from Ringgold past Cavetown and Mt. Pleasant to Keedysville, where it is cut out by a fault. The second area is of slight extent. Beginning about 2 miles east of Smoketown, it forms a low ridge or series of ridges to a point approximately 2 miles northeast of

Eakles Mills. The third area is due to a sharply compressed anticline which brings the Waynesboro formation to the surface in a narrow belt, parallel to the first, extending from $1\frac{1}{2}$ miles east of Mills, past Beaver Creek and Benevola, to a point less than 2 miles east of Sharpsburg.

The formation consists of sandstones, shales, and limestones. Near the base is a siliceous bed of limestone which weathers to a slabby porous sandstone, in the middle are dark-blue to white limestones, rich in magnesia, which grade upward with increase of silica into slabby sandstones and siliceous shales. The thickness, as estimated by Stose, is 1250 feet.

No operations were noted during a field study of this formation, but it is possible that with the development of the cement industry individual beds may be found suitable for mixture with the limestones of the region.

The Elbrook Formation.—The Elbrook formation consists of a series of bluish-gray limestones which are usually shaly or thin-bedded in the weathered outcrop, though appearing massive in the quarry face. Both the more magnesian and the more siliceous beds occur near the center of the formation, while near the top are conglomerate and so-called "edgewise" beds (see Plate XXII) indicative of an unconformity. The thickness of the formation is approximately 3000 feet.

The areal distribution of the Elbrook formation is limited on the east by the low ridges of the Waynesboro formation, and on the west by the relatively rugged topography of the Conococheague formation. The breadth of the area underlain by the Elbrook formation is approximately 2 miles on the Mason and Dixon Line. With this breadth it passes southwestward between Philo and Leitersburg across the Western Maryland Railroad to the Hagerstown-Funkstown electric line, beyond which point it begins to broaden on the west, ultimately merging with a somewhat detached area of the same formation separated by an infolding of the overlying Conococheague. This narrow western belt crosses the Western Maryland Railroad about midway between Bissell and Chewsville, with a breadth of about 1800 feet. South of the union of the two belts, at a point about $1\frac{1}{2}$ miles north of Breathedsville, the area occupied by the Elbrook formation widens to more than $3\frac{1}{2}$ miles in the

vicinity of Sharpsburg. The eastern boundary crosses the Potomac near the westerly bend between Antietam and Dargan. The western boundary, representing the contact between this formation and the overlying Conococheague, crosses the Potomac at Shepherdstown.

No quarries of importance are at present in operation in the Elbrook formation. Suitable beds occur, however, for the manufacture of both lime and cement, although most of the beds are high in magnesia. Pure limestone beds have been located at Chewsville by the Le Gore Lime Company, and property has been purchased there for the opening of a quarry and for the erection of kilns.

During the early days of natural cement manufacture this formation was more extensively worked perhaps than any other one of the Shenandoah group of limestones, as is evidenced by the old, abandoned quarries and mill of the Potomac Natural Cement Company located near the Potomac southwest of Sharpsburg.

The Conococheague Formation.—This formation consists of siliceous and argillaceous limestones which at a number of horizons are suitable for the manufacture of cement. Associated with these are white, drab, or dark magnesian beds. The low ridges marking the position of the base of the formation are due to limestone conglomerates and accompanying siliceous beds. The conglomerate consists of rounded limestone pebbles an inch or more in diameter, imbedded in a calcareous matrix. "Edgewise beds," so called because of their beds being composed of thin fragments of limestone tilted at different angles and held together by calcareous cement, also occur. The unconformable contacts are further marked by oolites and limestones with uneven clay partings. The weathering is also characteristic in that the massive dark-blue limestone which composes the body of the formation on large exposure shows on a gray background brown and yellow bands ranging from an inch in thickness to very thin laminae. This formation lies between the Elbrook below and the Beekmantown above, and has a thickness of about 1500 feet. It corresponds to the lower part of what was first described by Stose as the Knox limestone.

The Conococheague formation in Washington County occurs both east

and west of the Martinsburg shale belt. The eastern area enters Maryland from the north in a single broad band which, within 3 miles of the boundary, is separated into two areas by the intervening belt of Elbrook already described. The smaller easternmost area of Conococheague extends with an average width of about a mile to a point $1\frac{1}{2}$ miles north of Breathedsville. The larger central area extends southwesterly across the State with an average breadth of a trifle less than 3 miles. The western boundary of this area, except for a small re-entrant south of Hagerstown, may be described as a straight line running from Reid past Hagerstown and St. James to the Potomac River, which it crosses near the boundary between Jefferson and Berkley counties, West Virginia. The eastern limit is the contact with the Elbrook formation already described.

The area of Conococheague west of the Martinsburg shale is about 3000 feet broad on the Pennsylvania boundary, broadening to twice that amount where it is traversed by the Western Maryland Railroad, between Charlton and Big Spring.

Quarries have been opened on the Conococheague formation at a number of points to obtain stone for more or less local consumption, but the most important operation is between Bissell and the Western Maryland Railroad bridge across Antietam Creek. The company operating here is the Security Cement and Lime Company, which is at present increasing the capacity of its Portland cement mill from 800 to 2000 barrels per day.* On account of the character of its materials and the transportation facilities afforded by the Western Maryland, Norfolk and Western, and Baltimore and Ohio Railroads, the Conococheague formation probably gives greater promise of being extensively worked as a source of calcareous material for the manufacture of Portland cement than any of the other members of the Shenandoah group in Washington County.

A large quarry in the Conococheague formation is also operated by S. P. Angle in Hagerstown, northeast of the intersection of the Western

* A detailed description of this plant, the first erected in Maryland for the manufacture of Portland cement will be found on subsequent pages.

Maryland and Cumberland Valley Railroads. Practically the entire output of this plant is sold for railroad ballast, none of the stone quarried being burned into lime.

The Beekmantown Formation.—This formation consists of massive and finely laminated beds characterized by a varying, but usually high, content of magnesia and silica. Pure beds, however, occur, but are more abundant and thicker near the base where they are satisfactory for the manufacture of lime and cement, especially the latter. The horizon near the base marked by the occurrence of “edgewise” and siliceous beds similar to those in the Conococheague, is a transition zone which has been called the “Stonehenge” member. This member has not been represented on the map accompanying this report. The Beekmantown lies between the Conococheague below and the Stones River above, and has a thickness of about 2300 feet.

The Beekmantown formation crosses Washington County in three separate but parallel areas. The widest of the three lies to the east of the Martinsburg shale, while the two narrow belts lie to the west of it.

The largest of the three areas is approximately 4 miles wide, and occupies the territory between Hagerstown on the east and Williamsport on the west. It traverses the State as a broad belt from northeast to southwest, its eastern boundary being marked by its contact with the older Conococheague formation; while on the west the boundary line is the same as that which shows the contact between it and the overlying Stones River formation, except where, as at Williamsport, it is locally in contact with the Chambersburg through faulting.

The two narrower belts west of the Martinsburg shale are separated by the westernmost area of Conococheague. The more eastern of the two underlies the area between Charlton and its contact with the Stones River formation. This line of contact crosses the State in a northeast-southwest direction, and is about 2000 feet west of Pinesburg. The western boundary is marked by the contact with the Conococheague. The width of this area is approximately $1\frac{1}{2}$ miles. The more western of two belts, where traversed by the Western Maryland, is, however, wider than this, but diminishes in width northeastward.

The only quarries of any importance operated on the Beekmantown formation are those worked for the purpose of obtaining road metal, ballast, or stone for use in concrete. Within none of its three belts is the stone quarried and burned into lime, except for supplying a limited local demand. The larger of the two more important plants is located at Halfway, and at present (1909) is not in operation. When worked most of its output went to the Norfolk and Western Railroad for use as ballast. The smaller of the two plants is located on the Williamsport road between Halfway and Hagerstown, and the larger part, if not all, of its output is used in the manufacture of concrete blocks. The absence of lime or cement plants, however, should not be taken to indicate the absence of suitable materials. These occur, but at present are not utilized.

The Stones River Formation.—This consists of very pure dove-colored limestones, together with other beds high in magnesia. The purer beds of limestone occur at and near the top of the formation, and this is the portion which is most extensively quarried. The pure limestone above is followed by equally pure but thinner beds below, alternating with harder beds higher in magnesia. The beds high in lime may be identified where they project above the surface by their weathering into white, smooth, and rounded forms, and may be told by their velvety texture in fresh fracture and by their characteristic dove color. They yield a deep red soil, which is marked usually by a growth of cedars.* “Indeed, the presence of a considerable number of cedar trees in an area of Ordovician strata is quite a reliable sign that the underlying rocks are of Stones River age.” Because of this relationship it is sometimes referred to as the “cedar stone.”

The Stones River formation lies between the Beekmantown below and the Chambersburg formation above, and usually possesses a thickness of approximately 900 feet.

The areal distribution of the Stones River formation in Washington County is limited to narrow belts closely associated with the broader

* Bassler, R. S. *The Cement Resources of Va. west of the Blue Ridge*, p. 54.

[illegible]

FIG. 23.—Section showing geological structure across Hagerstown Valley (through Boonsboro). (R. C. Williams.)

east end of the stone bridge at Williamsport. The second, lying on the west side of the Martinsburg shales, is here separated from them by a narrow belt of Chambersburg. This second area of Stones River may be described as extending across the State from near Fairview to Pinesburg. The third, lying near the base of North Mountain, likewise extends across the State as a belt from a point just west of Dry Run to the Potomac at McCoys Ferry. This is bounded on the east by the underlying Beekmantown and on the west by a narrow belt of Chambersburg, until the latter is cut out by a fault near Green Spring Furnace. From the latter point to the river this fault is the boundary of the Stones River.

The Chambersburg Formation.—This formation consists of more or less pure argillaceous limestones and calcareous shales. The materials composing it pass from argillaceous limestones at the bottom to calcareous shales at the top. It lies between the Stones River formation below and the Martinsburg shale above. Its range in thickness is from 800 to 1000 feet.

The Chambersburg formation, like the Stones River formation to which in normal position it is superjacent, occurs on both sides of the broad belt of Martinsburg shale. A third belt crosses Washington County in a northeasterly direction from McCoys Ferry on the south, past Fairview, and thence follows the contact with a narrow belt of the Martinsburg shale that lies to the east of North Mountain to a point about $\frac{1}{2}$ mile west of Dry Run on the north. On the east it is in contact with the Stones River formation. The two belts first mentioned lie, respectively, east and west of the broad Martinsburg shale belt which crosses the Potomac at Pinesburg on the west and at Williamsport on the east. The Chambersburg belt to the east is of very limited extent, and only occurs at and in the immediate vicinity of Williamsport. West of the Martinsburg formation the Chambersburg formation is in contact with the former at Pinesburg Station, and is in contact on the west with the Stones River formation. It continues between the contact with the Martinsburg on the east and the Stones River on the west northeastward to the Mason and Dixon Line, continuing thence into Pennsylvania.

The chief value of the Chambersburg formation from an economic viewpoint lies in its argillaceous character and the composition of certain of its beds which are of such a nature that they are almost natural Portland cement mixtures. Suitable mixtures for the manufacture of Portland cement ought to be obtained without difficulty by adding to the material from the "cement beds" of the Chambersburg proper amounts of the pure limestone from the upper portion of the adjoining Stones River formation. So far, however, the Chambersburg formation, though possessing the potentiality just mentioned, has been put to no economic use whatever in Washington County.



FIG. 1.—QUARRY OF THE SECURITY CEMENT AND LIME COMPANY, SECURITY.



FIG. 2.—PLANT OF THE SECURITY CEMENT AND LIME COMPANY, SECURITY.

VIEWS OF PORTLAND CEMENT OPERATIONS, HAGERSTOWN VALLEY.

SHALE FORMATIONS.—The argillaceous material required in the manufacture of Portland cement may be found in the Hagerstown Valley in two geological formations—the Harpers shales, lying beneath and east of the limestones, and the Martinsburg shales, which occur in several belts across the State.

Harpers Shale.—The Harpers shale is exposed on the east side of the Hagerstown Valley in a belt running northeast and southwest, which is $\frac{1}{2}$ to $\frac{3}{4}$ of a mile wide, and in faulted contact on its west side with the Shenandoah limestone.

The Harpers formation consists of siliceous shales and intercalated beds of sandstone. The shales are bluish-gray in color, weathering to a light greenish-gray. The total thickness, which is not exposed at any one place, is estimated to be about 1200 feet.

Martinsburg Shale.—The Martinsburg shale overlies the Shenandoah limestone and, like the upper part of the Shenandoah group, is Ordovician in age. Three divisions have been distinguished by Stose, which are as follows:

Martinsburg formation.....	{ Eden.
	{ Utica.
	{ Trenton (upper part).

The Martinsburg formation is composed of thick beds of black and gray shales with thin, interbedded gray to greenish-gray and brownish-colored sandstones. The shales are usually fine-grained in texture and fairly uniform in composition over large areas. At and near the base of the formation they contain lime in amounts varying from about 2 to 10 per cent. The upper beds, however, are lower in lime and higher in silica, which ranges from about 50 to 65 per cent., while the sum of the alumina and iron is generally from 20 to 30 per cent. The thickness of this formation is between 700 and 1000 feet.

Distribution of Lime and Cement Materials in Hagerstown Valley.

CALCAREOUS MATERIALS.—The mineral resources of this region until recently have been little developed, compared with what they might be.

Quarries for limestone to be used locally and for burning into lime have long been operated, but most of the undertakings have been on a small scale. The individual quarries and certain of the more promising opportunities for future development are described in the following pages. These will be discussed according to the railroads which traverse the valley.

Western Maryland Railroad.—Beginning at the eastern end of this railroad, as it crosses the valley, the most important centers of operation are Cavetown, Security, Hagerstown, Williamsport, Pinesburg, and McCoys Ferry.

The quarry at Cavetown is owned and operated by *P. G. Zouck and Company*, who dispose of their product either as crushed stone for ballast or burnt lime for agricultural purposes. This quarry was sampled at two points. Sample No. 1, an analysis of which follows below, was taken to represent the lower 35 feet of the 50-foot breast of stone shown in the quarry:

ANALYSES OF LIMESTONE, P. G. ZOUCK AND CO.'S QUARRY, CAVETOWN.

	No. 1.	No. 2.
Silica (SiO_2)	.79	1.21
Alumina (Al_2O_3)	.94	.54
Iron oxide (Fe_2O_3)		
Lime (CaO)	48.49	50.07
Magnesia (MgO)	5.19	4.85
Ignition	43.95	43.65
Total	99.36	100.32

Near the center of the quarry where the sample, whose composition is given in analysis No. 1, was taken, the 8 to 10 feet of rock capping the rest is a flaggy-white to dove-colored limestone that breaks up on weathering, and when struck with a hammer, into small and more or less cube-shaped blocks. Under this band the limestone is blue to blue-gray and massive. It strikes N. 18° E. and dips 12° E. The total working face is about 50 feet high, but only the bottom 35 feet, as stated above, is represented in the sample.

A second sample of the Zouck Quarry was taken 150 feet west of where the first sample mentioned was obtained. In this sample is included 55 feet of stone, or all of the quarry face, with the exception of several feet of weathered material just under the thin cover of residual soil. The top portion of this 55 feet consists of 18 to 20 feet of dove-colored limestone, below which there is a blue to gray massive bed of limestone extending to the level of the floor of the quarry. The composition of this sample is represented by analysis No. 2.

Both analyses are quite low in clayey matter and high in carbonates so that when burned the stone yields a good quality of lime. Were it not slightly high in magnesia it would be suitable to manufacture into Portland cement.

About $\frac{1}{4}$ of a mile west of Cavetown, where there is a bridge across the railroad, a number of shaly limestone beds are exposed in the railroad cut for a distance of nearly 200 feet. These strike N. 20° E. and dip about 30° E., and underlie 125 feet of limestone which is blue on fresh fracture, and weathers to a gray to dove-colored surface, and is represented in the sample upon which the analysis below was made:

ANALYSIS (No. 3) OF LIMESTONE $\frac{1}{4}$ MILE WEST OF CAVETOWN.

Silica (SiO_2)	1.77
Alumina (Al_2O_3)	.73
Iron oxide (Fe_2O_3)	.45
Lime (CaO)	31.80
Magnesia (MgO)	19.51
Ignition	45.69
Total	99.95

At Chewsville there are some old openings in the limestone of the Elbrook formation on property which has recently been acquired by the *Le Gore Lime Company*. Samples were taken on the north side of the railroad 100 feet east of the station (No. 7), and north of the first cut east of the station (No. 8). These samples, on analysis, appeared very satisfactory, as may be seen from the following figures:

ANALYSES (Nos. 7-9) OF LIMESTONE FROM LE GORE PROPERTY, CHEWSVILLE.

	No. 7.	No. 8.	No. 9.
Silica (SiO_2)	1.20	1.10	1.40
Alumina (Al_2O_3)	1.50	.70	.94
Iron oxide (Fe_2O_3)			
Lime (CaO)	52.30	54.60	54.00
Magnesia (MgO)	2.35	.86	1.15
Ignition	43.56	* 43.68	43.51
Total	100.91	100.94	101.00

The establishment of a large cement plant at *Security*, a new station situated near the bridge over Antietam Creek about 2 miles east of Hagerstown, has attracted attention to the possibilities of cement manufacture in the State. Before locating at this point the company made careful examinations of many properties throughout the valley. The unusual size of the plant and the fact that it is the first modern Portland cement mill to be erected in Maryland, necessitates a more extended discussion of this area, which will be found under its proper caption on a later page.

The limestone deposits in the immediate vicinity of Hagerstown receive a slight advantage from their proximity to a center of building, but this is largely offset by a corresponding increase in the value of the surface of the land for building purposes, which deters operators from selecting these points for large operations, even when the quantity and quality of the beds are satisfactory.

The central and eastern portions of the city are underlain with limestones of the Conococheague formation, while limestones occurring along the western side of the city are of the Beekmantown formation.

Stone from the Conococheague is quarried by *S. P. Angle* for ballast and road metal.

Promising material conveniently situated with reference to transportation and accessible to suitable shale obtainable from the Martinsburg shale belt west of Williamsport or from the Harpers formation between Edgemont and Smithsburg, is found north of the Agricultural Fair Grounds (Nos. 50-51), Hagerstown, a short distance east of Potomac Avenue Station. Excellent material for the manufacture of cement also

occurs north of and near the junction of the Cumberland Valley and Western Maryland Railroads. Both of these locations have the disadvantage, however, of being rather far removed from water sufficient to supply a cement plant. In order to obtain necessary water for running a large plant the operator would be obliged to convey it by pipe from a pumping station located at some convenient point on Antietam Creek.

The chemical composition of the stone at the latter locality is shown in the following analyses:

ANALYSES OF CONOCOCHEAQUE LIMESTONE, CROSSING C. V. R. R. AND
W. MD. R. R., HAGERSTOWN.

	No. 52.	No. 53.	No. 54.	No. 55.	No. 56.
Silica (SiO_2)	7.52	16.04	14.33	4.28	5.51
Alumina (Al_2O_3)	3.05	5.27	4.89	.90	1.80
Iron oxide (Fe_2O_3)	.45	1.25	1.65	.86	.33
Lime (CaO)	48.92	41.30	42.94	52.29	51.85
Magnesia (MgO)	1.76	1.50	2.01	1.52	.32
Ignition	39.11	33.82	34.89	41.06	41.10
Total	100.81	99.81	100.71	100.91	100.91

52. Average of 132 feet below sample 53.

53. Average of 132 feet below sample 54.

54. Average of 132 feet below sample 55 beginning 175 feet N. Switch Tower.

55. Average of 175 feet beginning at Switch Tower.

56. Average of 75 feet west of Switch Tower.

Near Williamsport the juxtaposition of limestones and shales suggests favorable localities for cement manufacture. A sample of the Beekmantown limestone from a point east of the railroad station gave, on analysis, the following results:

ANALYSES OF BEEKMANTOWN LIMESTONE, WILLIAMSPORT.

	No. 67.	No. 68.
Silica (SiO_2)	6.04	4.46
Alumina (Al_2O_3)	1.29	2.13
Iron oxide (Fe_2O_3)	.58	.97
Lime (CaO)	49.63	47.55
Magnesia (MgO)	2.60	2.73
Ignition	40.65	41.44
Total	100.84	99.28

67. Sample taken 630 feet E. of freight station, Williamsport.

68. Average of 350 feet of limestone, Cushwa property E. of station.

Within the thickness represented in the sample on which the analysis above was made, individual beds may occur too high for use on account of their content of magnesia, but they could be located by closer analysis and eliminated in the process of quarrying.

The occurrence together of the raw materials and the favorable situation with respect to transportation by rail or canal render this region especially attractive and worthy of private investigation.

Limestone high in calcium oxide and low in magnesia occurs in contact with the "cement rock" of the Chambersburg formation at Pinesburg. Shale suitable for mixing for the manufacture of cement occurs within a few hundred yards, while an abundant supply of water is afforded by the proximity of this locality to the Potomac. The limestone, although stratigraphically below the purer upper portion of the Stones River formation, contains beds high in lime alternating with beds high in magnesia.

The principal operator at Pinesburg is the *Potomac Valley Stone and Lime Company*, operating two quarries, one for stone to calcine in its kilns and the other for ballast and crushed stone. In the latter quarry the stone, after it is blasted, is loaded into tram cars which carry it to the crusher, where it is broken down into suitable sizes. Most of this crushed stone is sold under contract to the Western Maryland Railroad and is used by the railroad for ballast. The limestone used in the manufacture of lime is from the Stones River formation and is very pure, as shown by the analysis (No. 75) below:

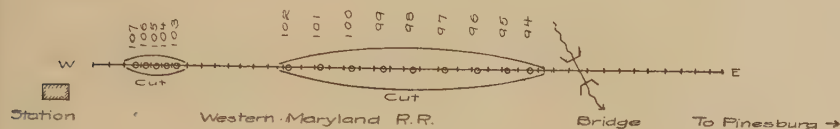
ANALYSES OF LIMESTONE FROM QUARRY OF THE POTOMAC VALLEY STONE AND LIME CO., PINESBURG.

	No. 75.	No. 76.
Silica (SiO_2)	.80	3.10
Alumina (Al_2O_3)	1.20	1.70
Iron oxide (Fe_2O_3)		
Lime (CaO)	53.00	47.25
Magnesia (MgO)	2.06	5.72
Ignition	43.40	43.14
Total	100.46	100.91

PARTIAL ANALYSES OF STONES RIVER LIMESTONE, PINESBURG.

	No. 77.	No. 78.	No. 79.	No. 80.	No. 81.	No. 82.	No. 83.	No. 84.
Silica (SiO_2)*	7.10	2.90	7.66	2.28	6.30	5.42	1.12	1.46
Alumina (Al_2O_3)	.98	1.10	1.04	1.74	1.82	1.60	1.56	1.04
Iron oxide (Fe_2O_3).....								
Lime (CaO)	44.44	43.33	40.93	44.26	48.99	45.27	51.70	52.91
Magnesia (MgO)	5.08	8.49	8.55	7.79	1.81	5.65	.69	.80
Ignition	40.25	43.14	41.33	43.09	40.20	41.53	41.09	42.15
Total	97.85	98.96	99.51	99.16	99.12	99.47	96.16	98.36

* Insol.



Sketch Showing
Location of Samples
Nos. 94 to 115.

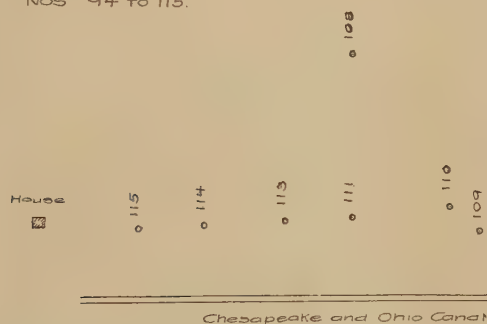


FIG. 24.—Sketch showing location of samples from McComas-Humrichouse farm, near Charlton.

Some of the beds would be satisfactory for Portland cement were they thick enough, while others that are sufficiently thick are too high in their content of magnesia. The same is true to a certain extent of the limestone on the *McComas-Humrichouse* farm, about 1 mile west of Pinesburg Station, where samples Nos. 94-115 were collected. The limestone on and between the McComas-Humrichouse farm and the

Potomac Valley Lime and Stone Company is overlain with a comparatively thin covering of soil, and it is not improbable that more detailed investigation of this area would lead to the discovery of limestone beds suitable for Portland cement, both as regards quantity and quality.

The areal distribution of the samples analyzed is shown in Figure 24, and the results obtained are given in the accompanying table:

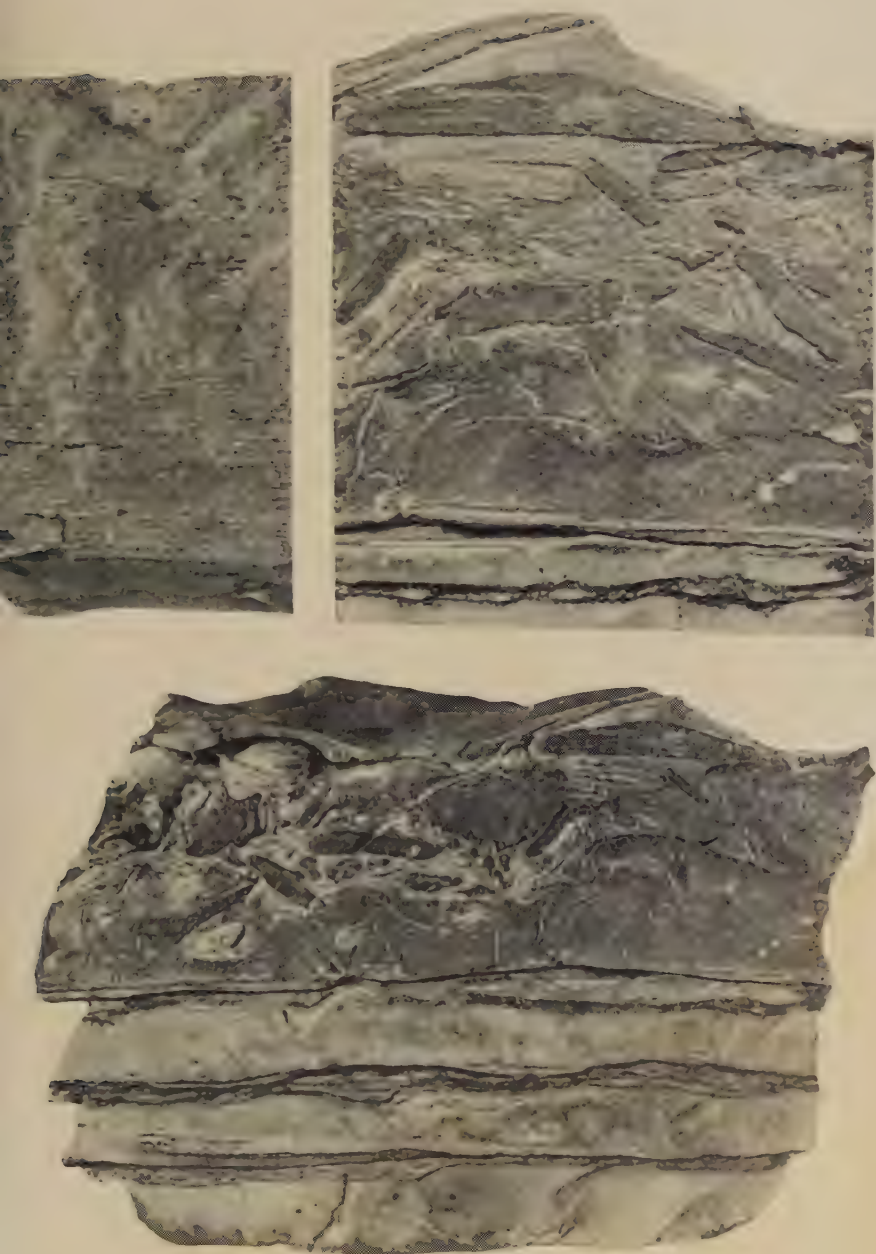
ANALYSES OF BEEKMANTOWN LIMESTONE, NEAR PINESBURG STATION.

Sample No.	Silica (SiO ₂).	Alumina (Al ₂ O ₃).	Iron Oxide (Fe ₂ O ₃).	Manganese (MnO).	Lime (CaO).	Magnesia (MgO).	Alkalies (K ₂ O+Na ₂ O).	Ignition.	Sulphur.	Water -100°C.	Total.
94	2.86	.28	.28	.04	52.24	2.05	.22	42.08	.03	.06	100.14
95	5.72	.12	.56	.06	51.28	1.01	.48	40.91	.01	.09	100.24
96	4.22	1.64	.28	.09	46.79	5.14	.85	41.50	.01	.02	100.04
97	2.72	.59	.16	.11	53.25	.87	.21	42.10	.03	.04	100.08
98	10.46	2.84	.72	.12	42.08	5.11	1.14	37.27	.11	.03	99.88
99	2.23	1.06	.24	.13	53.19	1.23	.28	41.61	.04	.03	100.04
100	14.17	3.17	1.00	.14	40.82	4.18	1.66	35.37	tr.	.04	100.05
101	4.61	.15	.64	.15	34.53	15.99	.09	44.07	tr.	.03	100.26
102	14.57	4.27	.90	.12	39.07	4.45	1.89	34.39	.09	.03	99.78
103	5.91	1.77	.56	.14	49.56	1.48	.74	39.62	.08	.05	99.91
104	16.20	3.36	.96	.20	39.56	3.44	1.66	34.05	.04	.07	100.04
105	10.62	1.70	1.12	.14	35.16	10.37	2.85	37.98	.07	.14	100.15
106	4.66	.84	.86	.16	51.42	.76	1.14	40.68	.04	.06	100.12
107	3.14	.24	.48	.09	51.94	1.61	.69	41.71	.04	.09	100.03
108	15.98	4.18	1.28	.06	37.50	5.69	1.37	33.39	.05	.17	100.17
109	14.28	2.06	1.20	.23	43.56	2.32	1.22	35.08	.04	.08	100.07
110	2.80	.51	.16	.10	53.06	1.17	.36	42.20	.14	.08	100.05
111	5.66	1.69	.52	.13	50.49	.71	.69	39.85	.10	.10	99.94
113	3.99	1.25	.32	.11	51.99	.65	.61	40.93	.17	.05	100.07
114	3.10	1.11	.32	.12	51.91	.85	.67	41.44	.13	.16	99.81
115	5.76	1.12	.92	—	49.86	.97	1.01	40.30	.12	.08	100.14

Cumberland Valley Railway.—Good material for cement manufacture occurs on the Cumberland Valley Railway near the bridge over the Potomac. The quality of the limestone at this point may be judged by reference to the following analyses:

ANALYSES OF BEEKMANTOWN LIMESTONE, C. V. RY., NEAR WILLIAMSPORT.

	No. 125.	No. 126.	No. 127.	No. 128.	No. 129.
Silica (SiO ₂)	6.60	10.80	7.80	4.10	4.00
Alumina (Al ₂ O ₃)	2.80	2.40	1.40	3.70	3.80
Iron oxide (Fe ₂ O ₃)					
Lime (CaO)	49.50	43.60	49.60	50.20	49.80
Magnesia (MgO)	1.81	4.13	1.55	1.19	1.41
Ignition	40.77	38.68	40.56	40.64	40.57
Total	101.48	99.61	100.91	99.83	99.58



"EDGEWISE BEDS" CHARACTERISTIC OF ELBROOK AND CONOCOCHIEAGUE FORMATIONS,
HAGERSTOWN VALLEY, WASHINGTON COUNTY.

Shale and an abundant water supply occur near at hand and transportation is afforded by the Cumberland Valley Railway and the Chesapeake and Ohio Canal. The success of a cement plant built here would depend largely on whether suitable arrangements could be made for rates over both the Cumberland Valley and the other railroad lines entering Hagerstown. In many respects this location is an excellent one.

Throughout its course through Maryland the Cumberland Valley Railway, both north and south of Hagerstown, traverses the surface of the Beekmantown formation in which are many beds of pure limestone. The quality of the beds at Hagerstown was given in the foregoing discussion. Little has been done in the way of developing quarries along this railroad because of the lack of favorable quarry sites arising from the interstream position of the railroad in Maryland. South of Williamsport, and near Maugansville are the only points where the line is across streams of any size where the natural trenches offer facilities for a water-free opening with any considerable quarry-face.

Norfolk and Western Railway.—Many excellent occurrences of limestone are found along the line of the Norfolk and Western Railway between Hagerstown and the Norfolk and Western bridge across the Potomac at Shepherdstown. Good exposure occur at many intermediate points.

Limestone beds outcropping on the hillsides near Grimes and Mondell and other small stations where the overburden of soil is insignificant could be quarried to great advantage and at a minimum cost. It is surprising, therefore, that there are not more quarries along this route, but the fact remains that few are in operation, and they are small and operated only intermittently. The chief objection, however, to cement sites along the Norfolk and Western Railway is the distance from a supply of shale, but by employing the proper machinery for preparation and mixing the material the residual soil might be used as a substitute.

Baltimore and Ohio Railroad.—The Washington County Branch, in passing from Hagerstown to Weverton, traverses diagonally the Conococheague and Elbrook formations, and crosses narrow bands of the Waynesboro and Tomstown formations. It is in a limestone area almost

continuously from Hagerstown to Trego. From a short distance north of the latter point to Weverton the country traversed consists of early Cambrian and pre-Cambrian formations. The limestones have been examined from Hagerstown to their contact with the underlying Antietam sandstone.

One of the most favorable localities for development is near Burtner, a flag station on the Baltimore and Ohio Railroad, about 2 miles south of Breathedsville. Here the limestone is well exposed in the hillside on the west of the railroad. Two samples were taken for analysis. The first of these (No. 130) represents beds of limestone aggregating 100 feet, which occur at the north end of the cut near the southern abutments of a trestle. The beds here strike N. 21° E. and dip 53° E. The second (No. 131) represents a thickness, carefully sampled foot by foot, of 150 feet of more or less argillaceous limestone outcropping northeast of the house on the farm owned by Miss Elizabeth Poffenberger. This outcrop is also on the west of the railroad not far from the southern end of the cut represented by the first sample. The analyses below show that the stone is fairly low in magnesia:

ANALYSES OF ELBROOK LIMESTONE, BURTNER STATION, 2 MILES S.
BREATHEDSVILLE.

	No. 130.	No. 131.
Silica (SiO_2)	8.71	8.36
Alumina (Al_2O_3)	1.89	2.76
Iron oxide (Fe_2O_3)	.32	.90
Lime (CaO)	45.37	46.42
Magnesia (MgO)	4.67	2.74
Ignition	39.46	39.39
Total	100.42	100.57

A second location apparently favorable for development is that near the bridge over the Antietam Creek. About 50 feet north of the western abutment of the bridge the railroad crosses a road and enters a cut in which the limestone beds are exposed, striking N. 25° E. and dipping 50° E. Sound rock is exposed for over 100 feet. This is followed by

an interval of an equal distance where the rock is too decayed or too heavily covered for satisfactory sampling. A second exposure of solid rock not quite as large as the first succeeds the zone of decay.

Analysis No. 137 represents a composite sample of beds aggregating 100 feet in the first solid portion; analysis No. 136 that of beds aggregating 80 feet from the second portion.

ANALYSES OF ELBROOK LIMESTONE, ANTIETAM CREEK, NEAR KEEDYSVILLE.

	No. 137.	No. 136.
Silica (SiO_2)	15.23	21.98
Alumina (Al_2O_3)	9.21	17.34
Iron oxide (Fe_2O_3)	1.65	2.67
Lime (CaO)	26.53	20.20
Magnesia (MgO)	11.55	4.61
Ignition	35.67	30.89
Total	99.84	97.69

While the four analyses given, especially the latter pair, are higher in magnesia than desirable, the abundance of limestones along the Baltimore and Ohio Railroad suggest the possibility of cement manufacture. The chief disadvantage in locating a plant on this road is the scarcity of good shales. This is not, however, as serious here as on the Norfolk and Western Railway since there is a possibility of using the shales of the Loudon formation which are crossed by the Washington County Branch near Rohrsersville. Suitable shale at this horizon is unfortunately poorly exposed.

ARGILLACEOUS MATERIALS.—The argillaceous materials available for mixture with the purer limestones for Portland cement manufacture occur in three general belts. On the east, lying near the western base of the Blue Ridge, are the shales of the Harpers formation, and in the southeast corner of the county, near Rohrsersville, shales of the Loudon formation. Both the Loudon and Harpers shales are likely to run too siliceous for this purpose, and to be poorly situated for working. Occasionally these objections are not serious. The following analyses represent an occurrence 660 feet east of a bridge east of Edgemont.

ANALYSES OF HARPERS SHALE, EDMONT.

	No. 1.	No. 2.
Silica (SiO_2)	62.80	60.88
Alumina (Al_2O_3)	20.22	20.90
Iron oxide (Fe_2O_3)	6.02	6.63
Lime (CaO)	1.10	1.00
Magnesia (MgO)	2.03	1.81
Ignition	4.00	3.70

Across the center of the valley is a broad belt of Martinsburg shale, the most suitable source of argillaceous components of the cement mixture in the county. Here the shales are fine-grained, relatively free from "quartz," and fairly uniform in composition. The character of these shales is well shown by the following table of analyses of shales from the property of the Security Cement and Lime Company.

ANALYSES OF MARTINSBURG SHALE, SECURITY CEMENT AND LIME CO.'S
PROPERTY, 1 MILE E. PINESBURG.

	No. 4.	No. 5.		No. 6.	No. 7.	No. 8.	No. 9.	
Silica (SiO ₂)	59.20	62.20	63.91	59.74	59.94	59.56	59.44	59.72
Alumina (Al ₂ O ₃) }	25.66	21.25	18.73	22.63	22.87	21.97	22.74	23.04
Iron oxide (Fe ₂ O ₃) . . . }		5.23	8.11	3.16	2.61	3.99	2.34	2.88
Lime (CaO)	3.16	.36	.00	.73	.64	.84	2.00	1.30
Magnesia (MgO)	2.04	.94	1.83	2.43	2.29	2.58	1.87	2.42
Ignition . . . . .	....	....	7.41	7.73	7.56	7.74	8.94	7.90

The location of plants in the Hagerstown Valley should have an advantage in freight rates over their nearest competitors of the Lehigh district of Pennsylvania and elsewhere outside of the State about sufficient to pay the dividends on their preferred stock. Hence it will be seen that limestone beds of the proper composition are well worth searching for, not only in this part of the State, but in all other sections where the location, quantity and quality of the material make it adapted for use in the manufacture of Portland cement. The recent financial depression has greatly restricted the building of cement plants and has resulted in an unprecedented reduction in the price of the product of operating plants, but, with the return of better conditions, there has been a slow but gradual increase in the price of Portland cement per barrel, and other plants are being built to supply and anticipate the ever-increasing

demand that under normal conditions has characterized the industry during the past 20 years.

*Security Cement and Lime Company.**

The Portland cement plant of the Security Cement and Lime Company is located at Security, a new station on the Western Maryland Railroad about 2 miles east of Hagerstown. It was completed and put in operation with its present capacity of 800 barrels a day during the summer of 1908. The plant was constructed by the Maryland Portland Cement Company, which combined in the fall of 1909 with the Berkeley Lime Company of West Virginia to form the present corporation. This new company is now increasing the capacity of the present plant so that when the enlarged plant is completed the daily capacity will amount to about 2400 barrels a day.

The raw materials of the Security Cement and Lime Company are limestone and shale. The company owns 131 acres of limestone land at Security, and a shale quarry near Pinesburg, some 10 miles distant. The cement mill is located on the limestone property and is built on the opposite side of the railroad from the quarry. The latter is opened on a natural quarry face 40 to 45 feet in height, situated on the east bank of Antietam Creek, and about 700 feet up the stream from the site of the plant. The stone from the quarry is conveyed to the crusher in cars traveling on a tram track paralleling the creek and passing under the bridge of the Western Maryland Railroad.

The limestone on this property varies in composition with different beds, but is uniformly low in the content of magnesia. Excepting a few thin beds in no case has the magnesia been found to exceed 3 per cent., and it is usually much below this, as may be observed from the table of analyses. Analyses 31-48 give the composition of the beds exposed along the railroad track at points 31 and 48 of the map, and of the beds that outcrop between these two points. Likewise analyses 16-23 and 24-30 give the composition of the beds at these and intermediate points at and

* Date furnished by J. S. Grasty.

in the vicinity of the quarry. The limestones on which these analyses were made vary in texture and composition, some being fine-grained, medium, hard, and blue and gray on fresh fracture, weathering to a light gray to dove color; others being more argillaceous weathering to a rough corrugated and banded surface. Both varieties are members of the Conococheague formation.

Owing to the manner in which the limestone has been folded here, the beds outcropping on the east side of the property are exposed near the center, and again near the western boundary. They strike N. 10° to

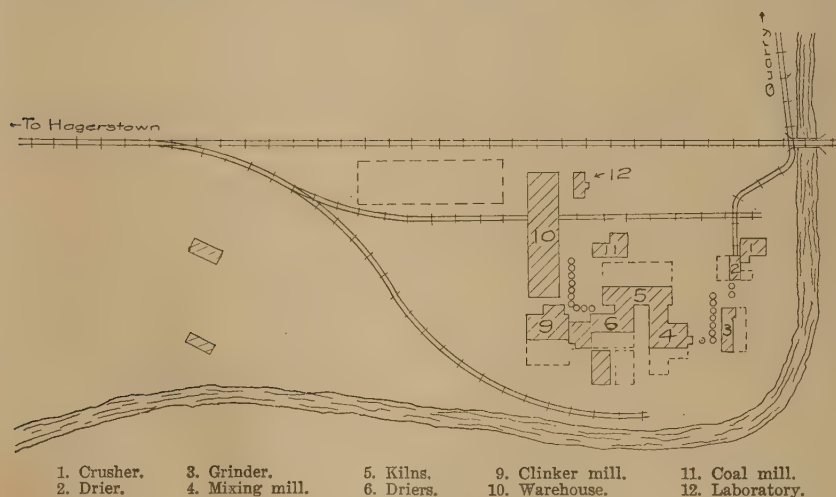


FIG. 25.—Plan of arrangement of buildings of Security Cement and Lime Company, Security.

15° E., and at the quarry dip 70° E. The axis of one anticline follows the direction (N. 10° to 20° E.) of the low ridge cut by the railroad between the station and the bridge, and the other, parallel to the first, crosses the railroad about 600 feet west of where the spur track to the plant turns off from the main line, or about 700 feet east of the company's station.

Antietam Creek, where it flows past the quarry, has cut into the flank of the first of the two anticlines mentioned above, and as a result has produced the natural quarry face already referred to. A synclinal fold

passes, as must be obvious from the foregoing, near the center of the property in a direction N. 10° to 15° E., and parallels the low ridge northeast of the station.

The following analyses of limestones and shale may be considered as typical of the composition of these materials on this company's two properties:

ANALYSES OF RAW MATERIALS USED BY SECURITY CEMENT AND LIME CO.

	Limestones			Shale		
		24.	28.			5.
Silica (SiO_2)	7.06	6.04	5.62	62.60	63.91	59.74
Alumina (Al_2O_3)	1.08	1.96	1.21	21.25	18.73	22.63
Iron oxide (Fe_2O_3)	1.01	.62	.81	5.23	8.11	3.16
Lime (CaO)	49.14	48.88	49.78	.36	none	.73
Magnesia (MgO)	1.70	1.74	1.58	.94	1.83	2.43
Ignition	40.02	39.30	40.96	....	7.41	7.73

It will be observed that besides the constituents being properly proportioned both in the limestone and shale each is very low in magnesia, while the former is quite high in its content of clayey matter.

Before the limestone and shale properties were purchased large samples of these materials were procured and shipped to well-known commercial chemists, Booth, Garrett and Blair, of Philadelphia, where, in their laboratory, it was made into Portland cement. The product was then tested, and the results obtained were satisfactory in every particular.

As was shown in the section on the calculation of cement mixtures, where two of the above analyses were used, only about 1 part by weight of shale is required here for 6 parts by weight of limestone. The amount of shale entering the mixture is thus seen to be relatively small because of the argillaceous content of the limestone. This is regarded as a great advantage in view of the fact that the shale must be hauled from a separate quarry.

The Security Cement and Lime Company is supplied with sufficient raw material to run its plant with its contemplated capacity of 2000 barrels a day for a very long period of years. Water, which is used in greater quantity by weight than any other raw material in cement manufacture, also exists in abundant supply on the company's property.

Fineness % passing.	Setting time.		Comp. of Pat.		Harden's time, days.			Tensile strength.	Specific gravity.	Chemical composition.								
	Initial.	Final.	Cement.	Sand.	% Water.	Air.	Water.			Total.	SiO ₂ .	Al ₂ O ₃ .	Fe ₂ O ₃ .	CaO.	MgO.	Alk.		
50	100	200	h. m.	h. m.														
I.	80.0	2 0	4 15		1	0	21	1	0	1	388	....	23.11	5.89	2.80	61.53	2.21	1.56
					1	0	21	1	6	7	779							
					1	0	21	1	27	28	870							
					1	0	21	1	38	89	918							
					1	3	8	1	6	7	366							
					1	3	8	1	27	28	425							
					1	3	8	1	88	89	480							
II.	93	3 0	5 30		1	0			1	1	204	3.2	....	....	....	2.83	1.16	
					1	0			7	7	514							
					1	0			28	28	698							
					1	3			7	7	189							
					1	3			28	28	268							
III.	95.8	77.0	1 25	3 40	1	0	21	1	0	1	385	....	23.04	5.81	2.41	61.38	1.61	1.60*
					1	0	21	1	90	91	765							
					1	0	21	1	6	7	776							
					1	0	21	1	27	28	831							
					1	3	9	1	6	7	265							
					1	3	9	1	27	28	387							
					1	3	9	1	90	91	426							
IV.	97.2	95.2	2 32	6 41	1	0	20		1	1	440	....	23.10	7.08	1.84	62.25	1.97	1.70†
					1	0	20		7	7	787							
					1	0	20		23	23	833							
					1	3	10		7	7	329							
									28	28	454							
V.	98.8	96.46	1 22	5 15				1	1	2	329	3.107	23.82	5.82	2.70	62.37	2.18	1.18†
								1	6	7	727							
									</									

* Ignition 2.86.

† " 2.06.

† " .56.

I. Tested by Booth, Garrett and Blair.

II. " B. F. Fendall.

III. " H. S. Spackman Eng. Co.

IV. " Osborn Eng. Co.

V. " H. C. Deming.

Below will be found the analysis of the cement actually made from the raw materials whose composition was given above. Along with the analysis an average analysis of seven other leading cement brands is submitted for comparison:

ANALYSES OF PORTLAND CEMENT.

	Analysis of Security Cement and Lime Co. brand.	Average analysis of 7 other established brands.
Silica (SiO_2)	21.72*	21.86†
Alumina (Al_2O_3)	7.66	7.19
Iron oxide (Fe_2O_3)	2.50	2.99
Lime (CaO)	62.91	62.42
Magnesia (MgO)	2.30	2.58
Sulphur dioxide (SO_2)	1.48	1.48
Total	98.57	98.52

* The analyses obtained in 1908 show higher content of silica with corresponding slower set and greater ultimate strength. This is due to the use of a slightly more siliceous limestone than that used in the calculations.

† Bull. No. 331, U. S. Geological Survey.

From the above analyses it is evident that the Security Cement and Lime Company is manufacturing a cement that is of the same composition as the best brands and, therefore, should, on its merit, be abundantly able to compete with these in the market.

The plant at Security is well located. The cement markets of Washington and Baltimore are near at hand, while five railroads center 2 miles from the plant at Hagerstown, and reach large sections of the States of Pennsylvania, Maryland, Virginia, and West Virginia. With a plant having five times the contemplated capacity of the one now building, this company would still be unable to supply the demand of the market which its strategic position ought to give it and other plants yet to be erected in Maryland.

In all Portland cement plants the work of machines is hard and continuous, and the wear and tear of machinery is unusually high. This is particularly true of machinery for clinker-grinding, and it may be readily imagined that the grinding of a close-grained and compact limestone, like that at Security is by no means an easy mechanical process.

A most important point in a cement plant, therefore, is to subdivide the process as skilfully as possible so that in case of a stoppage for repairs or adjustment of machinery at any point, or from any cause, the working of the plant as a whole will be interfered with as little as possible. It is important that the effect of these minor repairs or adjustments should be confined within narrow limits. For example: A belt may be slipping and need to be cut; a driving chain may come off a sprocket; an elevator or conveyor may choke at some point; a score of minor difficulties like these may occur from time to time. If the plant is so constructed that such repairs or adjustments would stop not only the features in question but make it necessary to stop a considerable number of other machines or any considerable part of the plant, the whole output of the factory would be curtailed to just that extent.

In designing the plant at Security, therefore, the purpose has been to have at every point machines with ample capacity, able to do considerably more than is regularly required of them. Then the power has been subdivided so that any machine or group of machines may be cut out without stopping the operation of any considerable amount of adjacent machinery. To supplement this and render it practically effective, large bin and storage facilities have been provided throughout the plant so that mills and kilns can continue in operation during all minor repairs.

The plant has also been designed so that all machines which must operate together in carrying out any part of the process are driven from the same power. This feature has very frequently been overlooked in cement plants. Elevators are driven from one line of shafting while the conveyor delivering to them is driven from another line of shafting. If either source of power stops the conveying system is out of commission. This is a very common error, and the essential cause for lack of efficiency in many plants. It is a little more trouble to carry power from one building to an adjacent building merely to reach an elevator, which nevertheless it is very important to do, as the stoppage of this elevator driven by some other source of power would stop the mills which preceded it.

In first cost, and also in operating cost, while running, the plant at Security, which is at present a comparatively small unit, would, no doubt, be most economically served by one large Corliss engine. But if this engine had to stop for all minor repairs and the whole plant stopped with the engine, it would be a most expensive installation by reason of loss of output and efficiency in the plant as a whole. Hence, for the purpose of differentiating the power and keeping all parts of the plant in operation continuously, and as far as possible independently of any localized delays or repairs, the Security plant has six engines and ten electric motors, connected up so that the particular processes which each has to deal with are not only independent of other processes but will be completely carried out from one source of power. In its other features it has the best machinery available on the market for the purposes in view, and as a complete plant unit it should have an unusual output. The general plans are for a plant having a capacity of 2500 barrels per day. The present installation is for 800 barrels per day, everything being placed in position for the larger unit.

The raw materials are mixed by weight as they come from the quarry, and this mixture of raw materials passes through the first process of reduction, which is a gyratory crusher. The raw material is then dried and afterwards ground by gradual reduction through suitable machines. There are large storage tanks between the crusher and the dryer and between the dryer and the rock mill. Moreover, there are large storage bins in the mills and in the kiln building. The kilns are 7 feet in diameter and within a few inches of 100 feet in length, each with a working capacity of about 400 barrels per day. Each kiln is supplied with a clinker cooler. There are also large storage tanks for clinker between the clinker coolers and the cement mill, and in connection with the latter bin capacity is provided of ample proportions.

The stock house has a cellular system of bins for storage and sampling of different lots of cement.

The company has two long trestles affording ample storage and cheap handling for coal, both for boiler and kiln purposes, and also for shale.

Natural Cement Operations.

Natural cement was formerly made in Washington County by the Potomac Cement Company, of Antietam, Maryland, and when mentioned, the mill or company, as the case may be, is usually referred to as the Antietam Cement Plant or Company. The mill, however, is not situated at the town of Antietam or on Antietam Creek, but on the Chesapeake and Ohio Canal a mile or more down stream from the bridge spanning the Potomac at Shepherdstown, West Virginia. The plant was started in 1888 by William H. Blackford and some Baltimore capitalists. It was built with a capacity of 300 barrels per day, but the average output according to available reports was about 200 barrels. Later the plant and property were sold to Washington parties, who now own them. They ceased operations in 1903. It is understood that it was never a financial success. At present the plant is in a very dilapidated condition, the retaining walls of the kilns having fallen away on one side.

ANALYSES OF LIMESTONE FOR NATURAL CEMENT, SHEPHERDSTOWN, W. VA.

	1	2	3
	Rock used.	Green Rock.	Gillmore Analysis.
Silica (SiO_2)	15.89	43.67	17.84
Alumina (Al_2O_3)	5.58	11.55	4.60
Iron oxide { (Fe_2O_3)	.74	.38	1.70
(FeO)	1.00	2.91	....
Lime carbonate (CaCO_3)	52.74	16.73	58.25
Magnesium carbonate (MgCO_3) ..	19.06	21.99	11.16
Alkalies ($\text{Na}_2\text{O} + \text{K}_2\text{O}$)	4.92	2.61	3.26
Sulphur (SO_3)	.31	0.00	.74
Phosphorus (P_2O_5)	.12	.19	....
Titanium (TiO_2) .....	....	.48	....

From the site of this mill may be seen, across the Potomac on the West Virginia side, the old mill of the Shepherdstown Cement Company, which is located about 1 mile east of Shepherdstown. The latter has not been in operation since 1900. Both mills based their operation on the use of an argillaceous and highly magnesian limestone having at both places about the same range in chemical composition. The above analysis made by the West Virginia Geological Survey is fairly indicative of the composition of the same beds of Cambro-Ordovician limestone

burned by the Maryland plant operating on beds of similar material that strike across the river and formerly were worked where the samples whose analyses are submitted above were taken.

The "green rock," whose composition is given in analysis No. 2, is so called by the quarrymen because of its characteristic color. According to Grimsley * it burns to a hard clinker and is not used on this account. Analysis No. 3 above is quoted from Gillmore † by Grimsley.

The Maryland mill and the West Virginia plant across the river produced cement of practically the same composition. The following analysis will, therefore, suffice to show about the average composition of both.

ANALYSIS OF NATURAL CEMENT, ANTIETAM.*

	Per cent.
Silica (SiO_2)	26.65
Alumina (Al_2O_3)	12.38
Iron oxide (Fe_2O_3)	2.14
Lime (CaO)	33.20
Magnesia (MgO)	12.56

* Mineral Industry, Vol. VI, p. 96.

The limestone is well exposed on both sides of the river. On the West Virginia side it rises to an elevation of about 125 feet, is little covered by residual soil, and could again be worked at moderate cost by the methods of quarrying by open cut, as was done on both sides of the river when these two cement mills were in operation. It is exposed for over a mile with beds of varying composition. The impurer beds of limestone are too high in magnesia to be used for Portland cement, but they could be neglected, while the purer beds might be worked to advantage. The residual soils a little distance back from the river could be obtained and employed to supply the argillaceous portion of the mixture, or Martinsburg shale might be had by a shipment of a distance of 12 miles by canal or Harpers shale on the Maryland side by shipping about a third as far. Suitable coal could doubtless be obtained at reduced cost by shipment by canal, which would furnish transportation by water to Washington for the finished product, and the facilities afforded

* Grimsley, G. P. W. Va. Geological Survey, Vol. III, p. 500.

† Limes, Hydraulic Cements and Mortars, 1872.

by the Norfolk and Western less than a mile away for rail transportation could also be utilized. To those interested in locating sites for Portland cement plants further investigation of the materials occurring in this vicinity might prove to be well worth both the expense and time spent.

WESTERN WASHINGTON COUNTY.

Geology.

The calcareous materials of the western part of Washington County are obtained from two formations, namely, the Cayuga and the Helderberg. The points where they may be worked at present, on other than a very small scale because of absence of transportation facilities, are confined to the outcrops on or near the Western Maryland Railroad. The younger of these two limestone formations, the Helderberg, is overlain by great masses of Devonian shale. The order of succession of these formations from top to bottom is

Devonian shale,

Helderberg limestone,

Cayuga limestone.

As the result of the movements which occurred at the close of the Carboniferous age, these formations and those that occupy positions either stratigraphically above or below them, were uplifted and folded into broad synclines and anticlines slightly overturned westward. Minor flexures are superposed upon these folds, resulting in the characteristic "Appalachian structure." The folds cross the State in a northeast-southwest direction, as may be seen from the geological map of the State.

CALCAREOUS MATERIALS.—The *Cayuga formation* is Silurian in age and lies between the older Niagara formation and the younger Helderberg. In Washington County it occurs in several areas from North Mountain westward, but has only been worked west of Hancock where certain of its beds have been mined and manufactured into natural cement. It may be divided into the following lithological units:

Thin-bedded and massive limestones at the top.

Shaly limestones and greenish shale.

Red sandstones and shale.

Drab shale and thin, interbedded limestones at the bottom.

The total thickness of the Cayuga is 1500 to 1600 feet. Two divisions have been recognized hitherto in the strata overlying the drab shales. The uppermost division, comprising about 110 feet, has been termed the Manlius member, while the strata underlying the latter and overlying the drab shales have been termed the Salina member. This division is based wholly upon the contained fossils and cannot be recognized by any differences in the character of the rocks. It will, therefore, not be discussed further at this place.

The drab shales forming the base of the Cayuga contains some calcareous beds but they are not important.

The strata overlying the red sandstones contain four cement beds, some of which have been extensively worked for the manufacture of cement, rendering the Cayuga formation of much commercial importance. It is well exposed at the works of the Round Top Hydraulic Cement Company, a few miles west of Hancock, on the Western Maryland Railroad, and also at another point on the same railroad a few hundred feet east of Dam No. 6 on the Potomac. The following analysis submitted below is furnished by Mr. Austin L. Gallagher, Industrial Agent of the Western Maryland Railroad, who had it made on a sample of limestone taken from the Tonoloway quarries near Dam No. 6:

ANALYSIS OF CAYUGA LIMESTONE, TONOLOWAY QUARRIES, DAM NO. 6, WEST OF HANCOCK.

Silica (SiO_2)	14.06
Alumina (Al_2O_3)	2.15
Iron oxide (Fe_2O_3)	.32
Carbonate of lime (CaCO_3)	79.85
Carbonate of magnesia (MgCO_3)	3.54
Organic	.08

Total100.00

Helderberg Formation.—The Helderberg limestone occurs at the base of the Devonian and the other formations of that system, being composed entirely of shales and thin-bedded sandstones. Some geologists refer the Helderberg to the top of the Silurian. It is exposed in Wash-

ington County on the Western Maryland Railroad, west of North Mountain, west of Hancock and east of Dam No. 6 on the Potomac. These points of outcrop are shown on the accompanying map.

The Helderberg consists of about 260 feet of beds of pure magnesian and argillaceous limestones, together with cherty limestone strata and a few beds of shale. Three divisions are recognized, known as the Coeymans, New Scotland, and Becraft members.

The *Coeymans* consists of heavy-bedded limestones usually very fossiliferous and with some cherty beds near its base. Among its fossils are very large *Stromatopora*, which weather into curly, nodular masses. The thickness of this member, which is the lowest one of the three, is about 110 feet.

The *New Scotland* or middle member of the Helderberg consists of massive beds of gray limestone with bands and stringers of chert. In some localities these massive beds of limestone become shaly and argillaceous owing to differences in the conditions of deposition under which they were originally formed. The thickness of this member is about 60 feet.

The Becraft, which is the top member of the Helderberg, consists of blue to gray limestones. Some of the beds toward the top are extremely cherty. The longer direction of the chert nodules, which vary in size, are arranged in parallel direction and occur as continuous and broken bands or ridges parallel to the bedding. Their greater resistance to erosion than the limestone in which they are imbedded results in their standing out against the limestone surface in parallel and more or less broken ridges.

ARGILLACEOUS MATERIALS.—The argillaceous materials of the western part of Washington County suitable for use in Portland cement mixtures are obtainable chiefly from the shales of Devonian age which overlie the calcareous materials. The shales are found in the following formations:

Jennings	{ Chemung. Portage. Genesee.
Romney	{ Hamilton. Marcellus.



FIG. 1.—VIEW OF FOLDED STRATA, ROUND TOP, NEAR HANCOCK.



FIG. 2.—OLD NATURAL CEMENT PLANT, ROUND TOP, NEAR HANCOCK.

VIEWS OF NATURAL CEMENT OPERATIONS, WESTERN WASHINGTON COUNTY.

Romney Formation.—The Romney formation overlies the Helderberg and occupies the middle section of the Devonian. It ranges from 1600 feet in thickness in Washington County to 500 and 600 feet beyond Wills Mountain, near Cumberland. This formation is divided into two members, the Marcellus member and the Hamilton member.

The *Marcellus* is the lower member of the Romney; in thickness it is about one-third that of the Romney. It consists of thin, black, papery, carbonaceous shales possessing marked fissility and easily crumpled between the fingers. Occasional thin beds of limestone occur in the higher portions of the formation some distance above its base. The Marcellus is easily eroded, and hence occupies the valleys and sides of valleys wherever it occurs in Maryland.

The *Hamilton* is the upper and thicker of the two members of the Romney. Its thickness is about two-thirds that of the entire Romney formation. It consists of green to greenish-black or brown shales and sandstones. Two heavy sandstone beds occur in it, one of which is found near the middle of the Hamilton. They stand out from the softer material and form noticeable topographic features. The Hamilton shales are inclined to be arenaceous. On weathering their dark color is lost and they become yellow and brown. This is particularly true of the upper part of this division, where the shales are also characterized by their tendency to break into irregular fragments. The lower part of the formation is difficult to distinguish from the upper section of the Marcellus, from which it is separated, on evidence furnished by fossils rather than by lithological differences.

The Upper Devonian comprises two divisions, the Jennings and the Hampshire formations, respectively. The former includes 4000 feet from bottom up, and the latter the next succeeding 2000 feet.

Jennings Formation.—The Jennings formation is divided into three members. The order of superposition from top to bottom is as follows:

Chemung.
Portage.
Genesee.

The *Genesee* consists of black fissile, argillaceous shales that weather to flat, dark plates and exhibit marked jointing like that seen in the

same formation in New York. This formation is absent in Washington County, but occurs further west in Allegany at the base of the Jennings.

The *Portage* is the middle member of the Jennings. It is composed of alternating shales and thinner sandstones and conglomerates interbedded with shales in the upper portion. The shales toward the base are usually argillaceous and fissile, becoming at higher horizons more arenaceous or sandy and olive-green in color. They weather into thin, flat plates, easily distinguished from the softer and hackly fractured fragments of the underlying Romney. The Portage is about 2000 feet thick and is connected by beds of passage with the overlying Chemung member.

The *Chemung* member of the Jennings formation overlies the Portage and occurs immediately below the Hampshire formation. It consists of sandstone, conglomerates and arenaceous shales. It contains several beds of conglomerates. The resistant character of these conglomerates results in their standing out as more or less prominent topographic forms. The thickness of the Chemung ranges from 1700 to 1800 feet.

Distribution of Lime and Cement Materials in Western Washington County.

The total thickness of the limestone formations in the western part of Washington County is nearly 1400 feet, while that of the shale reaches the enormous total of over a mile. Most of the calcareous material, however, is unsuited for making either lime or cement, though the greater part of the shale is of a composition such that with suitable deposits of limestone it could be readily utilized in a mixture for the manufacture of Portland cement. The only places in the western part of Washington County worth considering as locations for lime kilns to supply other than a local demand, or for cement plants, is where limestone in the former case and limestone and shale in the latter case outcrop along the Western Maryland Railroad, the only transportation route in this part of the county. The following are the several points that have been examined, the Cayuga, at Hancock and near the works of the Round Top Natural Cement Company, and some of the calcareous and

argillaceous material at Tonoloway Station on the Western Maryland Railroads, across the river from Great Cacapon, West Virginia.

HANCOCK DISTRICT.—The upper part of the Cayuga is quarried just beyond the western limits of Hancock, on the Warfordsburg Road, at locality No. 116 of the map. The small quarry sampled at this point is known as the Whitmeyer-Bridges Quarry. On fresh fracture the limestone exposed here is blue, weathering to a dove-gray color on the surface. Shaly limestone overlies and underlies the 50 feet of blue-gray massive limestone represented in the sample. This quarry is opened on the east side of the road going north. An analysis of the sample selected by the writers gave the following:

ANALYSIS OF CAYUGA LIMESTONE, WHITMEYER-BRIDGES QUARRY, HANCOCK.

	No. 116.
Silica (SiO_2)	5.65
Alumina (Al_2O_3)	2.57
Iron oxide (Fe_2O_3)	.68
Lime (CaO)	50.48
Magnesia (MgO)	.76
Ignition	40.17

Total 100.41

The composition of this material, as shown by the above analysis, indicates that it would be suitable to manufacture with shale into Portland cement. At present it is burned into lime.

A great thickness of Cayuga limestone is exposed both to the east and west, especially in the latter direction, from the closed plant of the Round Top Natural Cement Company. When this company was working, material was obtained by mining the four natural cement beds west of the plant. A sample was taken of the second bed west of the plant. This bed, which is a blue, argillaceous limestone, has a thickness of 12 feet. If other material of sufficient quantity and of the same composition could be found here, which is not at all improbable, it might result in the conversion of the abandoned works into a plant manufacturing Portland cement, since the analysis that follows shows that the material collected is a "cement rock" closely analogous in composition to those of Trenton age of the Lehigh district.

ANALYSIS OF CAYUGA LIMESTONE, SECOND CEMENT BED, ROUND TOP NATURAL CEMENT CO., HANCOCK.

	(No. 121.)
Silica (SiO_2)	20.16
Alumina (Al_2O_3)	6.34
Iron oxide (Fe_2O_3)	1.36
Lime (CaO)	38.56
Magnesia (MgO)	2.07
Ignition	31.74
Total	100.23

This cement rock, if a more detailed investigation should disclose it to be in greater quantity than it was found in the preliminary examination, might be used to make a suitable Portland cement mixture with limestone of the upper part of the Cayuga having the composition given above. Very little, however, of the latter would be required.

The works of the Round Top Natural Cement Company are situated between the railroad and canal. The plant was destroyed by fire in 1903, but was again rebuilt, with a capacity of about 300 barrels a day. The first cement in this district was made at this point in 1837.

TONOLOWAY DISTRICT.—Samples of Helderberg limestone and Devonian shale were taken at Tonoloway Station, which is at Dam No. 6 of the Potomac. Analysis shows that all of the material sampled there would be suitable to enter into a Portland cement mixture. The point where these samples were taken is indicated by the numerals 122 on the accompanying map.

Sample No. 122 represents 198.5 feet of Helderberg limestone. It includes the massive and highly fossiliferous crinoidal beds of the Helderberg and the adjoining 24 feet of the Cayuga. The beds dip 50° W. and strike $N. 25^\circ E.$ Sampling was begun 496 feet east of the railroad watch-house, which is 25 to 30 feet from Lock House No. 6, and includes the limestone between this point and a point $198\frac{1}{2}$ feet farther west. The analysis below shows that this material is truly a "cement rock" which could be burned into Portland cement with the admixture of a very small quantity of pure limestone. A second analysis made on a sample taken from the upper part of the Helderberg indicates that this part of the formation is high in magnesia.

ANALYSIS 1, HELDERBERG LIMESTONE, "CEMENT ROCK," TONOLOWAY OR DAM
No. 6.

	No. 122.
Silica (SiO_2)	21.72
Alumina (Al_2O_3)	5.88
Iron oxide (Fe_2O_3)	1.85
Lime (CaO)	36.91
Magnesia (MgO)	2.10
Ignition	30.91
Total	99.37

A sample of the black carbonaceous Romney shale representing 214 feet of material from beds dipping 80° W. was taken between the points 198 feet and 412 feet west of the west abutment of the bridge of the Western Maryland Railroad across Tonoloway Creek. The analysis follows below:

PARTIAL ANALYSIS OF ROMNEY SHALE, TONOLOWAY CREEK.

	No. 15.
Silica (SiO_2)	68.03
Alumina (Al_2O_3)	14.65
Iron oxide (Fe_2O_3)	6.17
Lime (CaO)	1.28
Magnesia (MgO)	.50
Ignition	4.24
Total	94.87

The Jennings formation outcrops west of Tonoloway Creek in contact with the underlying Romney. A sample was selected which consisted of olive-green and gray shales possessing rather marked fissility, but breaking into fragments with rough, hackly edges. It included 66 feet of material between the distances 1158 and 1224 feet west of Tonoloway Creek. The following is the analysis which, like that of the Romney given above, shows a composition satisfactory for mixing with limestone in the manufacture of Portland cement:

ANALYSIS OF JENNINGS SHALE, TONOLOWAY.

	No. 16.
Silica (SiO_2)	65.65
Alumina (Al_2O_3)	18.70
Iron oxide (Fe_2O_3)	5.91
Lime (CaO)	.65
Magnesia (MgO)	1.41
Ignition	5.16
Total	97.48

WASHINGTON COUNTY.
LIMESTONE.

Map No.	Name of limestone.	Quarry.	Nearest town.	Silica (SiO ₂).	Alumina (Al ₂ O ₃)	Iron (FeO)	lime (CaO).	Magnesia (MgO).	Ignition.	Total.	CaCO ₃ .	Analyst.
1/2	Towntown.		Leitersburg.	4.08	4.70		45.94	4.64	41.61	100.52	81.7	T. M. Price.
1	"	Zouck.	Cavetown.	.79	.94		43.49	5.19	43.95	99.35	86.4	E. G. Zies.
2	"	"	"	1.21	.54		50.07	4.85	43.65	100.32	89.1	E. G. Zies.
3	"	"	"	1.77	.73	.45	31.80	19.51	45.69	99.95	57.0	E. G. Zies.
4	"	Zouck.	"	0.74	6.93		50.97	0.35	40.43	99.47	90.6	T. M. Price.
5	"	"	"	12.00	4.42		46.54	0.44	36.78	100.18	82.8	T. M. Price.
6	"	"	"	11.13	8.00		44.03	1.24	35.70	100.10	73.3	T. M. Price.
7	Elbrook.	Le Gore.	Chewsville.	1.20	1.50		52.30	2.35	43.56	100.91	93.0	T. M. Price.
8	"	"	"	1.10	.70		54.60	.85	43.68	100.94	97.0	R. S. Williamson.
9	"	"	"	1.40	.94		.54	1.15	43.51	101.00	0.96	R. S. Williamson.
10	"	"	"	11.70	2.90		45.86	2.07	37.99	100.52	81.7	R. S. Williamson.
11	Conococheague.		Bet. Chewsville and } Security.	....	....	....	46.82	1.10	37.73	85.65	83.5	H. P. West.
12	"		Security.	....	....	....	41.68	2.70	35.48	79.86	74.2	H. P. West.
13	"		"	....	....	....	37.20	5.94	35.55	78.69	66.3	H. P. West.
14	"		"	....	....	....	46.38	5.82	42.53	94.73	82.6	H. P. West.
15	"		"	....	....	....	50.59	1.85	41.76	102.34	90.0	H. P. West.
16	"	S. C. & L. Co.	"	7.88	1.24	.80	48.05	1.41	40.35	99.73	85.6	J. J. Porter.
18	"	"	"	9.12	1.63	.53	43.97	.17	33.02	99.50	87.2	M. R. Schmidt.
19	"	"	"	6.33	.93	.44	50.47	1.20	40.50	99.90	89.8	M. R. Schmidt.
20	"	"	"	5.10	.86	.43	51.72	.84	41.03	99.93	92.0	M. R. Schmidt.
21	"	"	"	8.52	1.57	.56	47.94	1.78	39.95	99.42	85.9	M. R. Schmidt.
22	"	"	"	7.84	1.23	.69	49.69	1.11	39.39	99.95	87.4	M. R. Schmidt.
23	"	"	"	8.42	2.26	.63	48.35	1.34	38.83	99.83	86.2	M. R. Schmidt.

WASHINGTON COUNTY—Continued.

LIMESTONE.

Map No.	Name of limestone.	Quarry.	Nearest town.	Silica (SiO ₂).	Alumina (Al ₂ O ₃).	Iron (Fe ₂ O ₃).	Time (CaO).	Magnesia (MgO).	Ignition.	Total.	CaCO ₃ .	Analyst.
24	Conococheague.	S. C. & L. Co.	Security.	6.04	1.96	.62	48.83	1.74	39.30	98.52	87.0	J. J. Porter.
25	"	"	"	6.42	1.51	.49	46.73	1.77	40.70	99.67	86.9	J. J. Porter.
26	"	"	"	4.78	1.29	.61	49.50	2.38	41.18	99.75	88.1	J. J. Porter.
27	"	"	"	3.62	.69	.53	51.44	1.63	42.10	100.13	91.4	J. J. Porter.
28	"	"	"	5.62	1.21	.81	49.78	1.53	40.96	99.95	88.8	J. J. Porter.
29	"	"	"	5.60	1.04	.80	49.11	1.41	40.60	98.51	87.1	J. J. Porter.
30	"	"	"	7.66	1.29	.68	48.72	1.53	39.45	99.38	86.7	M. R. Schmidt.
31	"	"	"	7.28	2.37	.30	49.04	1.75	40.01	100.95	87.2	E. G. Zies.
32	"	"	"	9.52	1.75	.61	48.41	1.18	38.55	100.02	86.2	E. G. Zies.
33	"	"	"	11.24	2.92	.86	46.11	1.45	37.20	99.73	82.0	E. G. Zies.
34	"	"	"	15.31	3.40	1.18	42.85	1.31	35.60	99.65	76.4	E. G. Zies.
35	"	"	"	15.53	3.91	1.07	42.83	1.45	34.38	99.22	76.4	E. G. Zies.
36	"	"	"	14.14	3.57	.82	44.31	1.54	35.21	99.59	78.8	E. G. Zies.
37	"	"	"	12.68	3.33	1.08	43.98	2.24	36.26	99.57	78.3	E. G. Zies.
38	"	"	"	9.62	2.63	.65	46.52	1.66	38.44	99.52	82.8	J. J. Porter.
39	"	"	"	9.24	1.70	1.20	46.71	1.67	39.06	99.58	83.2	J. J. Porter.
40	"	"	"	5.22	....	.88	52.41	.54	41.15	100.20	93.2	E. G. Zies.
41	"	"	"	7.48	1.87	.69	47.99	1.25	39.92	98.31	85.5	J. J. Porter.
42	"	"	"	6.84	3.42	.67	47.03	1.65	39.94	99.30	83.7	J. J. Porter.
43	"	"	"	14.90	3.21	1.53	42.40	1.81	35.72	99.57	75.5	J. J. Porter.
44	"	"	"	10.80	2.88	1.12	46.45	1.80	37.50	100.55	82.7	J. J. Porter.
45	"	"	"	5.55	2.16	.81	49.87	1.18	39.99	99.56	89.0	E. G. Zies.
46	"	"	"	7.08	1.47	.81	48.12	2.03	40.52	100.08	85.6	J. J. Porter.

S. C. & L. Co.

WASHINGTON COUNTY—Continued.
LIMESTONE.

Map No.	Name of limestone.	Quarry.	Nearest town.	Silica (SiO ₂).	Alumina (Al ₂ O ₃).	Iron (Fe ₂ O ₃).	Lime (CaO).	Magnesia (MgO).	Ignition.	Total.	CaCO ₃ .	Analyst.
47	Conococheague.		Security.	5.55	1.60	.37	51.93	.69	40.61	100.51	92.4	E. G. Zies.
48	"		"	6.30	2.64		47.33	2.14	39.56	98.52	84.4	J. J. Porter.
49	"		Hagerstown.	10.32	3.64		46.42	2.23	38.30	100.95	82.6	J. J. Porter.
50	"		"	3.34	1.50		51.00	2.17	42.20	100.21	90.6	J. J. Porter.
51	"		"	3.16	1.71		47.25	5.72	41.86	99.64	84.3	R. S. Williamson.
52	"		"	7.52	3.05	.45	43.92	1.76	39.11	100.81	87.0	O. E. Bransky.
53	"		"	16.04	5.27	1.25	41.30	1.50	33.82	99.18	73.7	O. E. Bransky.
54	"		"	14.33	4.89	1.65	42.94	2.01	34.89	100.71	76.4	O. E. Bransky.
55	"		"	4.23	.90	.86	52.29	1.52	41.06	100.91	94.3	O. E. Bransky.
56	"		"	5.51	1.80	.83	51.85	.32	41.10	100.91	92.4	O. E. Bransky.
57	Beekmantown.		"	2.76	1.85	1.07	43.76	2.43	40.75	97.67	86.8	J. J. Porter.
58	"		"	11.16	3.59	.99	37.45	3.03	32.54	93.76	63.8	J. J. Porter.
59	Conococheague.		"	17.30	6.70		41.03	1.93	34.45	101.51	73.3	J. J. Porter.
60	"		"	19.40	5.30		40.80	1.43	33.53	100.46	72.8	R. S. Williamson.
61	"		"	12.70	3.80		45.50	1.59	37.40	100.99	81.0	R. S. Williamson.
62	Beekmantown.		Bet. Williamsport and Hagerstown.	n. d.	n. d.	n. d.	n. d.	2.26	....	....	....	R. S. Williamson.
63	"		"	"	"	"	"	3.04	....	....	....	R. S. Williamson.
64	"		"	"	"	"	"	4.53	....	....	....	R. S. Williamson.
65	"		"	"	"	"	"	16.23	....	....	....	R. S. Williamson.
66	"		"	"	"	"	"	18.30	....	....	....	R. S. Williamson.
67	"		Williamsport.	6.04	1.29	.53	49.63	2.60	40.65	100.84	88.4	Zies and Gill.
68	"		"	4.46	2.13	.97	47.55	2.73	41.44	99.23	84.6	J. J. Porter.

WASHINGTON COUNTY—Continued.
LIMESTONE.

Map No.	Name of limestone.	Quarry.	Nearest town.	Silica (SiO ₂).	Alumina (Al ₂ O ₃).	Iron (Fe ₂ O ₃).	Lime (CaO).	Magnesia (MgO).	Ignition.	Total.	CaCO ₃ .	Analyst.
69	Beekmantown.		Williamsport.	9.72	1.98	1.04	46.00	2.35	38.06	99.15	81.9	J. J. Porter.
70	Stones River.		"	3.86	1.26	.40	51.75	1.21	42.04	100.52	91.5	J. J. Porter.
71	"		"	4.76	.89	.51	50.31	1.94	41.80	100.21	89.5	J. J. Porter.
72	"		"	7.09	.99	.62	50.78	1.18	40.19	100.85	90.4	J. J. Porter.
73	"	Pot. Val. S. & L. Co.	Pinesburg.	.60	.96		55.00	n. d.	42.90	99.74	97.9	Zies and Gill.
74	"	"	"	.80	1.00	1.00	54.50	"	42.88	99.10	97.4	Zies and Gill.
75	"	"	"	.80	1.20	1.20	53.00	2.06	43.40	100.46	94.3	Zies and Gill.
76	"	"	"	3.10	1.70	47.25	5.72	5.72	43.14	100.91	84.2	Zies and Gill.
77	"	"	"	7.10*	.98	44.44	5.08	40.25	97.85	97.85	79.0	J. J. Porter.
78	"	"	"	2.90*	1.10	43.33	8.49	43.14	98.96	98.96	77.3	J. J. Porter.
79	"	"	"	7.66*	1.04	40.93	8.55	41.33	99.51	99.51	73.0	J. J. Porter.
80	"	"	"	2.28*	1.74	44.26	7.79	43.09	99.16	99.16	78.9	J. J. Porter.
81	"	"	"	6.30*	1.82	43.99	1.81	40.20	99.12	99.12	87.4	J. J. Porter.
82	"	"	"	5.42*	1.60	45.27	5.65	41.53	99.47	99.47	80.6	J. J. Porter.
83	"	"	"	1.12*	1.56	51.70	.69	41.09	96.16	96.16	92.5	J. J. Porter.
84	"	"	"	1.46*	1.04	52.91	.80	42.15	98.36	98.36	94.3	J. J. Porter.
85	"	"	"	12.70*	2.46	44.02	1.43	35.96	96.62	96.62	78.3	J. J. Porter.
86	"	"	"	7.40*	2.88	30.59	16.67	25.69	83.23	83.23	54.5	J. J. Porter.
87	"	"	"	11.74*	4.40	42.17	2.31	35.43	86.05	86.05	75.1	J. J. Porter.
88	"	"	"	5.40*	1.30	43.78	2.93	40.89	99.05	99.05	86.9	J. J. Porter.
89	"	"	"	4.90*	1.40	49.61	2.03	40.93	98.87	98.87	87.3	J. J. Porter.
90a	"	"	"	9.90*	1.82	47.54	1.99	39.27	100.52	100.52	84.6	Catlett and Porter.
90b	"	"	"	6.62*	1.50	45.06	5.65	41.36	100.19	100.19	80.1	Catlett and Porter.

* "Insol."

WASHINGTON COUNTY—Continued.
LIMESTONE.

Map No.	Name of limestone.	Quarry.	Nearest town.	SiO ₂ .	Alumina (Al ₂ O ₃).	Iron (Fe ₂ O ₃).	lime (CaO).	Magnesia (MgO).	Ignition.	Total.	CaCO ₃ .	Analyst.
91	Stones River.		Pinesburg.	2.96*	.84		53.00	1.00	42.44	100.24	94.3	Catlett and Porter.
92	"		"	2.44*	1.20		53.03	1.30	42.79	100.76	94.3	Catlett and Porter.
93	"		"	4.43*	1.42		40.10	11.69	32.56	90.25	71.4	Catlett and Porter.
94	Beekmantown.		Charlton.	2.86	.28	.28	52.24	2.05	42.08	100.14†	93.0	A. J. P., U. S. G. S.
95	"		"	5.72	.12	.56	51.28	1.01	40.91	100.24†	91.3	A. J. P., U. S. G. S.
96	"		"	4.22	1.64	.28	46.79	5.14	41.50	100.04†	83.6	P. H. Bates.
97	"		"	2.72	.59	.16	53.25	.87	42.10	100.08†	94.8	P. H. Bates.
98	"		"	10.46	2.84	.72	42.08	5.11	37.27	99.88†	75.1	P. H. Bates.
99	"		"	2.23	1.05	.24	53.19	1.23	41.61	100.04†	94.7	P. H. Bates.
100	"		"	14.17	3.17	1.00	40.32	4.18	35.37	100.05†	71.7	P. H. Bates.
101	"		"	4.61	.15	.64	34.53	15.99	44.07	100.26†	61.5	P. H. Bates.
102	"		"	14.57	4.27	.90	39.07	4.45	34.39	99.73†	69.7	P. H. Bates.
103	"		"	5.91	1.77	.56	49.56	1.48	39.62	99.91†	88.3	P. H. Bates.
104	"		"	16.20	3.56	.96	39.86	3.44	34.05	100.04†	71.1	A. J. P., U. S. G. S.
105	"		"	10.62	1.70	1.12	35.16	10.37	37.93	100.15†	62.6	A. J. P., U. S. G. S.
106	"		"	4.66	.84	.36	51.42	.76	40.68	100.12†	91.5	A. J. P., U. S. G. S.
107	"		"	3.14	.24	.48	51.94	1.61	41.71	100.03†	91.4	A. J. P., U. S. G. S.
108	"		"	15.98	4.18	1.28	37.50	5.69	33.89	100.17†	66.9	A. J. P., U. S. G. S.
109	"		"	14.28	2.05	1.20	43.56	2.32	35.08	100.07†	77.6	A. J. P., U. S. G. S.
110	"		"	2.30	.51	.16	53.06	1.17	42.20	100.08†	94.5	P. H. Bates.
111	"		"	5.66	1.69	.52	50.49	.71	39.85	99.94†	89.9	P. H. Bates.
112	"		"	3.99	1.25	.32	51.99	.65	40.93	100.07†	92.6	P. H. Bates.
113	"		"	3.10	1.11	.82	51.91	.85	41.44	99.81†	92.4	P. H. Bates.
114	"		"	5.76	1.12	.92	49.83	.97	40.30	100.14†	89.0	A. J. P., U. S. G. S.
115	"		"									

† Includes MnO; Alkalies: SO₃; H₂O.

* "Insol."

WASHINGTON COUNTY—Continued.
 LIMESTONE.

Map No.	Name of limestone.	Quarry.	Nearest town.	SiO ₂	Alumina (Al ₂ O ₃)	Iron (Fe ₂ O ₃)	lime (CaO).	Magnesia (MgO).	Ignation.	Total.	CaCO ₃	Analyst.
116	Cayuga.		Hancock.	51.65	2.57	.68	50.48	.76	40.17	100.41	89.9	E. G. Zies.
117	"		"	3.80	4.00		50.14	1.16	40.65	99.75	89.2	T. M. Price.
118	"		Round Top.	19.81	7.35	2.41	35.76	3.18	30.29	97.80	63.8	C. Richardson.
119	"		"	27.1	1.5		36.40	2.52	31.16	98.98	64.7	C. Huse.
120	"		"	26.07	11.40	3.17	28.05	3.44	25.94	98.17	50.0	E. G. Zies.
121	"		"	20.16	6.84	1.36	28.55	2.07	31.74	100.23	50.9	E. G. Zies.
122	Helderberg.		Gt. Cacapon.	21.72	5.88	1.25	36.91	2.10	30.91	99.37	65.0	E. G. Zies.
123	"		"	19.71	6.33	1.48	34.06	6.47	31.84	99.89	60.8	E. G. Zies.
124	Beekmantown.		Grimes.	3.60	1.80		51.00	2.39	42.41	101.20	90.8	R. S. Williamson.
125	Stones River.		Williamsport.	6.60	2.80		49.60	1.81	40.77	101.48	88.3	R. S. Williamson.
126	"		"	10.80	2.40		43.60	4.13	38.68	99.61	77.6	R. S. Williamson.
127	"		"	7.80	1.40		49.60	1.55	40.53	100.91	88.3	R. S. Williamson.
128	"		"	4.10	3.70		50.20	1.19	40.64	99.83	89.4	R. S. Williamson.
129	"		"	4.00	3.80		49.80	1.41	40.57	99.58	88.6	R. S. Williamson.
130			Butner.	8.71	1.89	.32	45.37	4.67	39.46	100.42	80.9	Zies and Gill.
131			"	8.35	2.76	.90	46.42	2.74	39.39	100.57	82.7	Zies and Gill.
133	Conococheague.		Grimes.	8.50	3.20		47.05	2.68	39.45	100.88	83.8	R. S. Williamson.
134			"	9.48	1.71	.75	46.85	2.30	38.54	99.63	83.6	O. E. Bransky.
135			Keedysville.	3.21	4.21		51.44	.34	40.72	99.92	91.0	T. M. Price.
136			"	21.38	17.84	2.67	20.20	4.61	30.89	97.69	36.0	Zies and Gill.
137			Antietam.	15.23	9.21	1.65	26.53	11.55	35.67	99.84	41.2	Zies and Gill.
138			Sharpsburg.	3.40			47.60	5.32	43.10	100.76	84.8	R. S. Williamson.
139			"	1.79	3.49		46.65	5.49	42.65	100.08	83.2	T. M. Price.
140			"	15.97	7.59		23.72	15.60	20.22	83.10	42.2	C. Richardson.
141			"	19.20	8.30		23.20	9.78	29.24	99.82	41.3	R. S. Williamson.

THE LIMESTONES OF MARYLAND

WASHINGTON COUNTY.											
ARGILLACEOUS MATERIALS.											
Map No.	Name of shale.	Nearest town.	Silica (SiO ₂).	Alumina (Al ₂ O ₃).	Iron (Fe ₂ O ₃).	Lime (CaO).	Magnesia (MgO).	Alkalies.	Ignition.	Total.*	Analyst.
1	Harpers.	Edgemont.	62.80	20.22	6.02	1.10	2.03	....	4.00	....	J. J. Porter.
2	"	"	60.88	20.9	6.63	1.00	1.81	....	3.70	....	
3	Martinsburg.	Hagerstown.	59.46	20.24	4.82	1.09	1.77	....	9.52	96.90	J. J. Porter.
4	"	"	59.20	25.66		3.16	2.04	....	....	....	J. J. Porter.
5	"	"	59.74	22.63	3.16	.73	2.43	....	7.73	96.42	J. J. Porter.
6	"	"	59.94	22.87	2.61	.64	2.29	....	7.56	95.91	
7	"	"	59.56	21.97	3.99	.84	2.53	....	7.74	96.68	J. J. Porter.
8	"	"	59.44	22.74	2.34	2.00	1.87	....	8.94	97.33	J. J. Porter.
9	"	"	59.72	23.04	2.88	1.30	2.42	....	7.90	97.26	J. J. Porter.
10	"	"	62.20	19.01	7.47	.20	.94	....	6.24	95.86	J. J. Porter.
11	"	Pinesburg.	64.23	21.23	4.97	.62	1.72	1.25	5.09	100.11	A.J.P., U.S.G.S.
12	"	"	53.53	18.75	6.27	4.66	2.71	1.92	6.59	100.06	A.J.P., U.S.G.S.
13	"	"	59.20	25.66		3.16	2.04	....	....	....	J. J. Porter.
14	"	"	50.96	25.63	4.27	5.40	2.43	....	10.14	98.83	J. J. Porter.
15	Romey.	Gt. Cacapon, W. Va.	68.03	14.65	6.17	1.28	.60	....	4.24	94.87	E. G. Zies.
16	Jennings.	"	65.65	18.70	5.91	.65	1.41	....	5.16	97.48	E. G. Zies.

*Analyses incomplete.

SUMMARY AND STATISTICS FOR WASHINGTON COUNTY.

The limestones of Washington County are most abundantly developed in the Hagerstown Valley where they have been worked especially along the Western Maryland Railroad, the largest operations being at Cave-town, Hagerstown, Halfway, and Pinesburg. Other quarries and numerous kilns are found scattered over the valley.

The exposures of satisfactory limestones are frequent in the western portion of the county, but few of them are capable of commercial development on account of their present inaccessibility. Where the various limestone strata cross the lines of the Western Maryland Railroad and the Chesapeake and Ohio Canal these deposits are accessible and offer many opportunities for the development of cement, lime, and stone industries.

Washington County ranks first in the production of limestone for ballast, road-metal, concrete, etc., due to the large railway mileage and demand for crushed stone in railroad construction and maintenance. In spite of the fact that the county contains a great abundance of limestone in areas traversed by several railroads, it ranks third in the production of lime. One of the reasons why the amount of lime made in Washington County is small in proportion to the available raw material is because the average quantity of lime used for agricultural purposes is less per acre of area than it is in any of the other four principal lime-producing counties in the State, with the exception of Allegany. Moreover, its distance from Baltimore and Washington, the two leading markets for building lime, prohibits the Washington County lime operators from entering into strong competition with the producers who are located nearer these two markets.

The inception of a new industry—that of manufacturing Portland cement—at Security has aroused renewed interest in the resources of the region. With the promised success of this plant, and others which may follow, the value of the annual production of cement will greatly exceed that of any other forms in which the limestones are used. At present the annual production of lime is valued at \$20,000, and the crushed

stone at from \$65,000 to \$100,000, depending upon the demand for material in railroad and highway construction.

The list that follows below gives the names of the large as well as the small lime and limestone producers operating within the limits of Washington County:

LIME AND LIMESTONE OPERATORS IN WASHINGTON COUNTY.

OPERATOR.	OFFICE.	QUARRY.
Angle, S. P.	Hagerstown	Hagerstown.
Besore, Geo. N.	Smithsburg	Smithsburg.
Beverly Granite Co.	Beverly, S. C.	Halfway.
Brown and Bachtell.	Smithsburg	Edgemont.
Clarkson Brothers	Hagerstown	Hagerstown.
Creeger, J. Wesley.	Thurmont	Thurmont.
Hagerstown City Quarry.	Hagerstown	Hagerstown.
Hagerstown Macadam Co.	"	"
Horst, D. E.	Maugansville	"
Hose, Geo. W.	Clear Spring	Dry Run.
Keedy, D. D.	Keedysville	Rohrersville.
Little, Frank P.	Hancock	Hancock.
McKee, James F.	Clear Spring	Clear Spring.
Md. Ala. Marble Co.	New York	Benevola.
The Md. Quarry Co.	Williamsport	Williamsport.
Miner, George F.	Smithsburg	Edgemont.
Moser, Joseph F.	Thurmont	Thurmont.
Nutter, Daniel R.	Maugansville	Maugansville.
Potomac Valley Stone Co.	Hagerstown	Pinesburg.
Rines, L. C.	Eakles Mills	Boonsboro.
Rohrer Bros.	Smithsburg	Smithsburg.
Shinham, Geo. W.	Hagerstown	Cearfoss.
Smith, Vernon T.	Lewistown	Thurmont.
Strock, J. C.	Hagerstown	Cearfoss.
Union Stone Co.	York, Pa.	Halfway.
Wade, J. Hubert.	Roonsboro	Sharpsburg.
Washington Marble Co.	New York	Eakles Mills.
Zouck, P. G. & Co.	Cavetown	Cavetown.

ALLEGANY COUNTY.

GEOGRAPHICAL LIMITS.

The area embraced within the limits of Allegany County is high and mountainous. It is crossed along its southern border by the Western Maryland Railroad, while a portion of this county is also traversed by the Baltimore and Ohio. Other lines centering at Cumberland by following valleys and by taking advantage of the gaps in the mountains, tap the coal-fields, and furnish a means of transportation into Pennsylvania.

GEOLOGY.

The rocks exposed in Allegany County range in age from Silurian to Carboniferous. These have been folded into major synclines and anticlines, upon which are minor flexures of a similar sort. Faults are also known to occur, but, as a rule, the normal stratigraphy has been but little disturbed by them. The nature of the folding is well shown in the gap cut by Wills Creek through the mountain of the same name just west of Cumberland. Synclines alternate with anticlines throughout the whole of this area, but the deformation becomes less pronounced passing from east to west.

The geological formations of Allegany County of special interest in the present discussion are as follows:

	Limestones.	Shales.
Carboniferous.....	Greenbrier.....	Mauch Chunk.
Devonian.....	Helderberg.....	{ Hampshire.
		{ Jennings.
		{ Romney.
Silurian.....	Cayuga.	

The geological characteristics of each of these formations, with the exception of the Carboniferous Greenbrier limestones and Mauch Chunk shales, have been described in detail in the preceding discussion of Washington County, and need not be redescribed for Allegany County where they present the same general features.

The limestone and shale formations of Allegany County cross it in a northeast and southwest direction, and are generally traversed by the railroads at more or less acute angles to the strike of the formations by reason of the fact that the railroad routes have been controlled principally by the topography. But this is immaterial, so far as the shales are concerned, because of their great thickness and wide distribution; it has, however, an important bearing on the commercial development of the limestones, which are much thinner than the shales, and have their workable areas restricted and confined to a few localities. The sections in which the limestones are exposed to best advantage for quarrying occur in the valleys east and west of Wills Mountain. The Helder-

berg and Cayuga limestones are both worked on the east side of this mountain in the vicinity of Cumberland. To the west of Wills Mountain they are well exposed along the lines of the Baltimore and Ohio and Pennsylvania Railroads, between Mt. Savage Junction and Corriganville, while the same beds have been worked further southwest on their strike at Potomac, where they are crossed by the Baltimore and Ohio and Western Maryland railroads. Between Rawlings and Dawson the Helderberg is exposed along both transportation routes for a distance of about 5 miles. This is because these two lines follow the formation across an anticlinal area for considerable distances parallel to the strike. The Helderberg is also well exposed on the Baltimore and Ohio Railroad northeast of Dawson, where the quality of the stone is probably such as to make it valuable for use in the manufacture of cement or for burning into lime.

In cement manufacture the Devonian shales are the most accessible for use in conjunction with Cayuga and Helderberg limestones. On the other hand, the Carboniferous shales are most advantageously situated with reference to the Greenbrier limestone.

Limestones.

The Greenbrier formation belongs to the Mississippian or lower division of the Carboniferous. Stratigraphically, it is above the Pocono sandstone and beneath the Mauch Chunk red shale, and usually occupies valleys or sides of valleys which are flanked by ridges upheld and maintained by the more resistant Pocono.

In Maryland the Greenbrier limestone is probably the least important economically of all the limestone formations. However, if followed southwestward into West Virginia, it grows thicker and purer, and becomes of increasing commercial importance. In Maryland it attains a thickness of about 300 feet and consists mainly of shales, but contains also beds of limestone and sandstone. The beds of limestone are inclined to be siliceous, becoming more sandy near the contact of this formation with the Pocono. Their color is gray and brown, and when weathered the more siliceous layers stand out as minor ridges,



FIG. 1.—GREENERIER LIMESTONE, WEST OF CORRIGANVILLE.



FIG. 2.—HELDERBERG-CAYUGA LIMESTONES, DEVIL'S BACKBONE, CORRIGANVILLE.

VIEWS OF ALLEGANY COUNTY LIMESTONE EXPOSURES.

while the less sandy parts between occur as furrows. This corrugated weathering is shown in Plate XXV, Fig. 1.

The Greenbrier limestone crosses transportation routes in Allegany County at but three points. The first of these is $1\frac{1}{4}$ miles east of Barrellsville, on the Cumberland and Pennsylvania Railroad; the second is 3 miles east of Eckhart Mines, on the same road as the above, which is paralleled at this point and further east by the Georges Creek and Cumberland Railroad; the third is about 2 miles east of Westernport.

Shales.

The most important of the argillaceous materials of Allegany County are of Devonian age. These occur widely distributed and closely associated with the Helderberg and Cayuga limestones, as shown on the geological map of the State. In general, the chemical composition of these shales is such as to make it quite an easy matter to locate deposits suitable for Portland cement manufacture.

The fact that the base of the Romney formation is separated stratigraphically from the Helderberg by a thickness of only about 350 feet of Oriskany sandstone, while the latter rests, in turn, on the Cayuga formation, assures the economic assembling of limestone and shale at a Portland cement plant built at some convenient point on or between these calcareous and argillaceous formations.

The Devonian shales of Allegany County differ in no essential respects either as regards chemical composition or physical characteristics from the shales of the same age already described as occurring in Washington County. In both counties, but particularly in Allegany, they attain an enormous thickness and cover much larger areas than any of the other formations that are found intimately associated with them.

DISTRIBUTION OF LIME AND CEMENT MATERIALS OF ALLEGANY COUNTY.

Cayuga and Helderberg Limestones.

CORRIGANVILLE.—Northeast of Corriganville the Pennsylvania Railroad passes through the gap made by Wills Creek in the high ridge that

parallels Wills Mountain on the west. The railroad cuttings expose both the Helderberg and the Cayuga, the former in contact with the Oriskany sandstone on the west.

After the railroad tracks pass round the ridge in question they follow in a northeastern direction on and close to the contact of the Oriskany and Romney shale all the way to the Pennsylvania-Maryland line. On the west side of the ridge, where the tracks curve sharply from west to north, the railroad company owns and operates a large quarry from which the lower cherty strata of the Oriskany are quarried and crushed for ballast. Analyses of samples of this material are as follows:

ANALYSES OF ORISKANY CALCAREOUS CHERT, CORRIGANVILLE.

	No. 6.	No. 7.	No. 8.	No. 9.
Silica (SiO_2)	48.54	53.21	56.07	69.82
Alumina (Al_2O_3)	5.50	4.22	4.02	4.97
Iron oxide (Fe_2O_3)	2.21	1.66	1.26	1.59
Lime (CaO)	22.29	21.98	20.88	13.76
Magnesia (MgO)	1.05	.55	.46	.10
Alkalies ($\text{Na}_2\text{O} + \text{K}_2\text{O}$)	1.50	n. d.	n. d.	n. d.
Ignition	18.23	18.09	16.98	10.38
Total	99.32	99.71	99.17	100.62

The location of their occurrences are indicated by corresponding numbers on the general map. From these analyses it will be seen that the Oriskany is increasingly less siliceous the nearer its beds are to the base of the formation where it is in contact with the Helderberg.

In cutting through the ridge referred to above, Wills Creek has left on its north side a sharp and steep escarpment. The strata stand almost on end. One of the beds rising higher than the rest from a thickness of 16 feet at the level of the railroad track, narrows down to a sharp and ragged edge that cuts through the very crest of the cliff, and stands out as a most striking topographic feature. This has been given the name "Devil's Backbone," and is famous as a bit of local scenery. A photograph of the "Devil's Backbone," is reproduced as Plate XXIV, Figure 2.

Samples were taken of the "Devil's Backbone" and certain of the accompanying beds, as shown in the diagram, Figure 26. The bed of

limestone called the "Devil's Backbone" is Helderberg in age. Its position in the formation is indicated in the following measured section, which gives the succession of beds from the topmost down. The contact of the Helderberg in the "Devil's Backbone" ridge with the Oriskany sandstone on the west, is just back of the section house.

Beginning with the bed of the Helderberg in contact with the Oriskany the first 64 feet in the section quoted below are assigned to the New Scotland, or middle member of the Helderberg, the Becraft, or the upper member, being absent at this point. The lower 110 feet are referred to the Coeymans.

HELDERBERG LIMESTONE SECTION AT DEVIL'S BACKBONE.

NEW SCOTLAND.

	Thickness feet.
(a) Soft and bluish argillaceous shales with some indurated layers. Occasional manganese phosphatic nodules.....	20
(b) Massive-gray limestone with bands of chert becoming thin-bedded above and containing beds of shales.....	44

COEYMANS.

(c) Massive regularly bedded blue-gray limestone. (The sharp ridge of the "Devil's Backbone.") (Analysis No. 5½).....	16
(d) Thin bed of shaly limestone.....	1½
(e) Massive regularly bedded, blue-gray to dove-colored non-fossiliferous limestone. (Analysis No. 5).....	22
(f) Heavy-bedded gray nodular limestone filled with <i>stromatopora</i> known as the "first stromatopora bed." (Analysis No. 4).....	1½
(g) Heavy-bedded blue limestone almost without <i>stromatopora</i> . (Analysis No. 3).....	25
(h) "Second stromatopora bed" abounding in a few species of corals	9
(i) Thin-bedded nodular limestone with occasional <i>stromatopora</i> ...	10
(j) Heavy-bedded grayish limestone with layers of chert more prominent above than below. Fossils are rare. (Analysis No. 2)....	32½

All of the Coeymans, the lower member of the Helderberg section at the "Devil's Backbone," was sampled, as stated in the foregoing, with the exception of the 19 feet above the 32 feet of heavy-bedded, grayish limestone at the base of the formation. One reason why this 19 feet was not sampled was because of the close lithological similarity of most of it to the first *Stromatopora* bed. The analysis of the latter may,

therefore, be taken to indicate the approximate composition of the former.

The upper 40 feet of Cayuga limestone, underlying the Coeymans of the Helderberg, the one grading almost imperceptibly into the other, consists of blue, cherty limestone above and massive limestone at the bottom, with soft and shaly beds between.

A sample of this was taken, and its composition is represented by analysis No. 1.

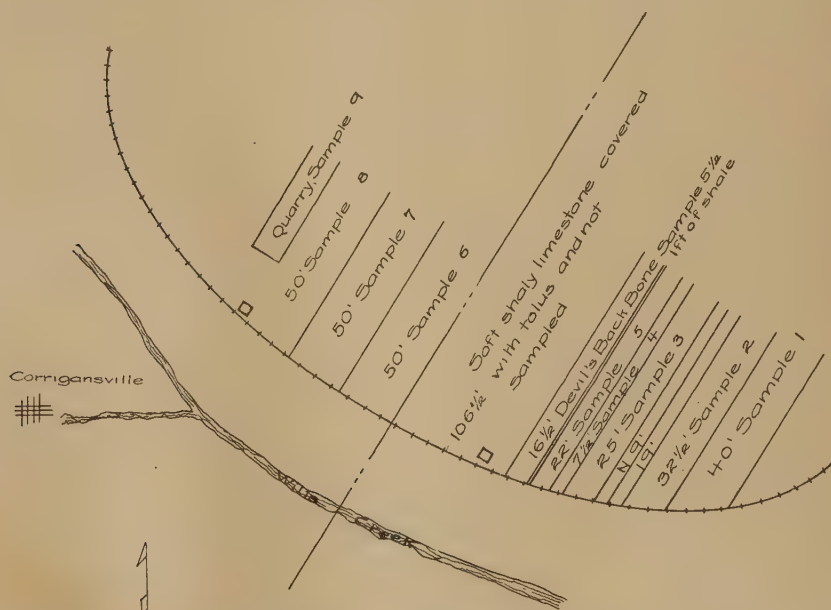


FIG. 26.—Diagram showing source of samples analyzed from Corriganville, Maryland.

The following gives the average composition of the set of samples described above:

AVERAGE COMPOSITION OF HELDERBERG LIMESTONE AT "DEVIL'S BACKBONE,"
CORRIGANVILLE.

Silica (SiO_2)	13.43
Alumina (Al_2O_3)	2.10
Iron oxide (Fe_2O_3)	.83
Lime (CaO)	45.10
Magnesia (MgO)	1.41
Ignition	37.01
Total	99.88

Stone of the above composition would require the admixture of very little shale of correct composition to manufacture into Portland cement. Such shales could be had near at hand from the Romney formation, a 120-foot sample of which was taken west of Corriganville, on the road to Barrellsville, at No. 1 of the map.* Material of the same composition may be had on the line of the Baltimore and Ohio Railroad.

ALLEGANY GROVE.—Another place where limestone occurs of suitable composition for Portland cement is at Cash Valley, west of Wills Mountain, between Allegany Grove and Narrows Park. This point is about midway between the two stations in the small gap in the ridge nearly $\frac{1}{2}$ mile west of where the Eckhart Branch of the Cumberland and Pennsylvania Railroad crosses to the east side of the turnpike. The Helderberg limestone has been quarried here and burned into lime.

The analysis quoted below was made on a 66-foot sample taken at the point indicated by No. 16 on the map. The limestone exposed here was found to be cherty near the top, massive near the middle, and shaly below:

ANALYSIS (NO. 16) OF HELDERBERG LIMESTONE, CASH VALLEY, NEAR ALLEGANY GROVE.

Silica (SiO_2)	12.01
Alumina (Al_2O_3)	1.54
Iron oxide (Fe_2O_3)	.75
Lime (CaO)	47.06
Magnesia (MgO)	1.05
Ignition	37.69
Total	100.10

West of the quarry, where the sample analyzed above was obtained, Romney shales occur in great abundance, and in conjunction with limestone like that above could be used to manufacture Portland cement.

CUMBERLAND.—The same limestone formations that were sampled at the "Devil's Backbone," near Corriganville, occur along transportation routes on the east of Wills Mountain at Cumberland. Both the Helderberg and the Cayuga have been quarried here and made into lime, and

* See shale analysis No. 1.

the former also into natural cement by the Cumberland Hydraulic Cement and Manufacturing Company. The Cumberland Hydraulic Cement and Manufacturing Company is capitalized at \$2,000,000, and has a plant with a capacity of 1000 barrels in 10 hours. The cement mill is located at Cumberland and is equipped with ball and tube mills, so that the natural hydraulic cement clinker in grinding is put through a quadruple process with the same sort of machinery as that employed in grinding Portland cement, producing an equal fineness in the product. Cement was first made here in 1836. The quarries are in the south bank of Wills Creek, where the Helderberg rocks are so folded and exposed that the beds can be conveniently worked. The following is a fairly typical but poor analysis of the material used:

ANALYSIS (No. 13) OF CAYUGA LIMESTONE, "NATURAL CEMENT ROCK,"
CUMBERLAND.

Silica (SiO_2)	24.74
Alumina (Al_2O_3)	16.74
Iron oxide (FeO)	6.30
Lime (CaO)	23.41
Magnesia (MgO)	4.10
Alkalies ($\text{Na}_2\text{O} + \text{K}_2\text{O}$)	6.18
Sulphuric acid (H_2SO_4)	2.22
Ignition	18.99
Total	102.68

POTOMAC.—The works of the Cumberland and Potomac Cement Company are at Potomac, or "Pinto," on the Baltimore and Ohio Railroad 9 miles west of Cumberland. The plant is situated on the north side of the railroad, and was first operated in 1891. The raw materials are obtained from the cement beds of the Cayuga and burned directly into natural hydraulic cement. The works have a capacity of 600 barrels a day.

The "4th cement bed" is on the north side of the railroad, and about midway between the plant and the railroad bridge over the Potomac-Cresaptown road. When the plant is in operation argillaceous limestone is mined from this, and the three other beds that occur in the Cayuga. A sample of the "4th cement bed" was taken. This in-

cluded the 15 feet of the material between the foot and hanging walls, on which the mud cracks that were formed at the time of their original deposition may be clearly seen.

ANALYSIS (No. 18) OF CAYUGA LIMESTONE, "NATURAL CEMENT ROCK, 4TH CEMENT BED," POTOMAC.

	No. 18.
Silica (SiO_2)	17.60
Alumina (Al_2O_3)	5.66
Iron oxide (Fe_2O_3)	3.01
Lime (CaO)	35.44
Magnesia (MgO)	4.77
Ignition	32.74
Total	99.22

The Cayuga limestone near the works of the Cumberland and Potomac Cement Company might be used also in the manufacture of Portland cement. It occurs of suitable quality and in good form for quarrying at the point where the Baltimore and Ohio Railroad crosses the Potomac-Cresaptown road, about $\frac{1}{4}$ of a mile or more west of the plant. Here three samples of limestone were taken, which represent an aggregate thickness of 141 feet of stone. The strike of the beds is N. 45° E. and their dip 45° W.

Sample (No. 27) was taken east and across the road from the house owned by Mr. Rawlings, north of the grocery store near the railroad. The 47 feet of material included in this sample consisted of dove-to-gray-colored limestone, blue on fresh fracture, with occasional thin beds more or less shaly. The analysis shows that it contains very little magnesia, and being high in silica would require a small amount of shale when it comes to mixing the two to manufacture Portland cement:

ANALYSES OF CAYUGA LIMESTONE, POTOMAC.

	No. 27.	No. 28.	No. 25.
Silica (SiO_2)	11.26	9.11	7.30
Alumina (Al_2O_3)	2.39	2.18	1.85
Iron oxide (Fe_2O_3)	.97	.99	.87
Lime (CaO)	47.03	47.76	49.65
Magnesia (MgO)	.88	.96	.88
Ignition	37.56	38.82	39.59
Total	100.09	99.82	100.14

The next sample, No. 26, was obtained representing 44 feet of limestone, massive above and thin-bedded and shaly below, situated stratigraphically below sample No. 27. This analyzed as indicated.

Sample No. 25 represents 50 feet of heavy, bedded limestone lying below the preceding, the top bed of which crosses the railroad at the east abutment of the bridge previously mentioned. The bottom ledge lies to the east of a small spring on the north side of the railroad track.

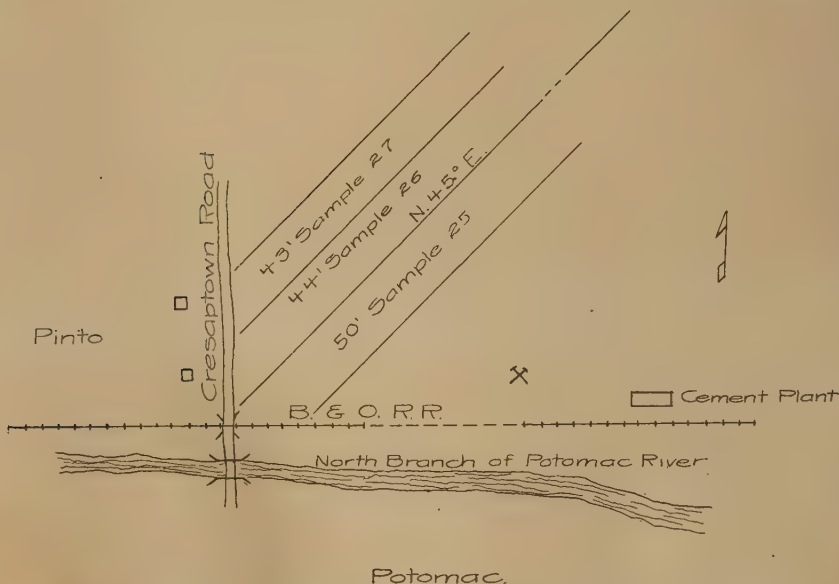


FIG. 27.—Diagram showing source of samples analyzed from Potomac, Maryland.

Utilizing this limestone, which is strikingly similar in composition to that on the property of the Security Cement and Lime Company at Security, about 2 miles west of Hagerstown, the plant of the Cumberland and Potomac Cement Company might, by the installation of the necessary machinery, again be put into operation manufacturing Portland cement. Both shale and argillaceous limestone are also near at hand.



FIG. 1.—QUARRY OF CUMBERLAND HYDRAULIC CEMENT COMPANY, CUMBERLAND.



FIG. 2.—QUARRY OF CUMBERLAND AND POTOMAC CEMENT COMPANY, POTOMAC.

VIEWS OF ALLEGANY COUNTY CEMENT ROCK QUARRIES.

The plant would be at a disadvantage in being situated further from the principal markets of the State than some of its competitors, but it would control the western markets of Maryland and the markets of the adjoining sections of West Virginia and Pennsylvania, and would have an advantage over other works located further east, in the matter of fuel, which the Potomac plant might get from West Virginia at a much cheaper rate.

RAWLINS.—The following analyses were made on samples of limestone taken west of Rawlins on the Baltimore and Ohio. The first of the samples (No. 28) was selected so as to include a stratigraphic thickness of 20 feet, the beds of limestone represented dipping east, with the hanging wall above, a distance of 3750 feet, measured along the tracks of the Baltimore and Ohio Railroad west of Rawlins. Several other samples were taken stratigraphically below this first one. In the second sample (No. 30) 25 feet is represented, and in the third (No. 31) and fourth (No. 29) 34 and 60 feet, respectively; or, in other words, a total consecutive thickness of 134 feet. The foot wall of the beds included in sample (No. 29) is marked by a *Stromatopora* bed which, according to the recent work of Dr. T. Poole Maynard, indicates the line here between the Coeymans and the Cayuga.

The beds of limestone referred to above as having been sampled at the points mentioned,* rise abruptly above the level of the railroad. But here, on the convex side of the first large bend of the Potomac west of Rawlins, where the samples were taken, the topography is such that with two railroads at the base of the cliff occupying the only level area between a steep acclivity on the one side and the river on the other, the opening of a quarry would at first be fraught with some difficulties. However, these could be overcome. The analyses of the samples taken are as follows:

* Analyses following below.

ANALYSES OF LIMESTONE SAMPLES, 1 MILE W. RAWLINS.

	No. 28.	No. 29.	No. 30.	No. 31.
	Thickness of stone represented.			
	20 feet.	60 feet.	24 feet.	34 feet.
Silica (SiO_2)	30.61	13.47	12.95	11.72
Alumina (Al_2O_3)	.62	2.69	.47	1.19
Iron oxide (Fe_2O_3)	.70	.95	.68	.75
Lime (CaO)	38.08	43.11	47.71	46.54
Magnesia (MgO)	.81	3.37	.90	2.34
Ignition	29.94	37.21	37.53	38.07
Total	100.76	100.80	100.24	100.61

DAWSON.—The Helderberg limestone is well exposed at a number of other points along the West Virginia Central and Pittsburg Railroad, also on the Baltimore and Ohio Railroad. From a point about 1 mile west of Rawlins the two parallel tracks are within a stone's throw of each other, diverging about a mile beyond Black Oaks to meet and cross one another, and to continue parallel again beyond Dawson. Throughout the distance between the points just mentioned, the two roads follow in their alignment for stretches of considerable length the general strike of the Helderberg formation. About a mile southwest of Black Oaks the Baltimore and Ohio and the West Virginia Central Railroads diverge, as stated above, the former following closely on a surface contour, and so turning from a more southerly course sharply to the west, while the latter has a straight stretch of track from the point of divergence to its bridge across the river. Samples were taken of three successive thicknesses of the thin-bedded and much-folded, more or less, argillaceous ledges of limestone exposed in the side cut in the hill on the north side of the Baltimore and Ohio Railroad, about 500 feet west of the point of curve mentioned in the preceding sentence. The analyses of these samples is given below. The first (No. 32) was taken between an upper stratum, or hanging wall, dipping east and striking across the track 500+ feet west of the point of curve just referred to, and further marked by the emergence from the rock at this point of a small but persistent spring, and the footwall stratigraphically 95 feet below. While it in turn is followed below by samples (Nos. 33-34), respectively, representing 65 and 60 feet. Analysis (No. 35) was made on a bulk sample repre-

senting the limestone formerly worked in the small, abandoned quarry on the west side of the Baltimore and Ohio, and about $\frac{3}{4}$ of a mile along the track northeast of Dawson:

ANALYSES OF CAYUGA LIMESTONE, BETWEEN DAWSON AND BLACK OAK,
BALTIMORE AND OHIO RAILROAD.

	No. 32.	No. 33.	No. 34.	No. 35.
	Thickness.			
	95 feet.	65 feet.	60 feet.	50 feet.
Silica (SiO_2)	3.69	3.82	10.67	9.17
Alumina (Al_2O_3)	1.27	.75	1.28	.90
Iron oxide (Fe_2O_3)	.62	.58	1.16	.72
Lime (CaO)	51.51	51.06	44.55	49.36
Magnesia (MgO)	1.04	1.56	3.28	1.60
Ignition	41.65	41.36	37.86	39.08
Total	99.78	99.13	98.80	100.83

From the above analyses it may be seen that the Helderberg limestone of the anticlinal area under discussion, particularly that portion of it between Black Oak and Dawson, is worthy of careful consideration and investigation on the part of those having in mind the erection of Portland cement plants in the western part of the State. Shale, water, fuel, and transportation facilities are all four here close at hand. It is reported that land has already been bought along the line of the West Virginia Central Railroad, between Dawson and Black Oaks, with the view of erecting a Portland cement plant to use the limestone exposed further southwestward along the strike in West Virginia.

Greenbrier Limestone.

At none of the few points where the Greenbrier limestones occur in Allegany County on railroads is it fit for use for much else than as a road-metal, ballast, and the like. It is usually too siliceous to make into lime and too limited in quantity, even when otherwise suitable for use in the manufacture of cement. Samples were taken at two points, one about $1\frac{1}{4}$ miles east of Barrellville, on the north side of the Barrellville-Corriganville road, and the other on Stony Run.

BARRELLVILLE.—The samples near Barrellville were taken from a quarry operated principally for the purpose of furnishing road-metal for

use on the section of the turnpike from Corriganville to Barrellville. This quarry is located at (No. 10) and is well shown in Plate XXIV, Figure 1. It has a working face of $29\frac{1}{2}$ feet high, including a band of shale $11\frac{1}{2}$ feet thick that separates the limestone into two ledges of about equal thickness. The beds strike N. 25° E. and dip 20° W., and are worked also on the south side of the railroad which is on the opposite side of Jennings Creek. The sample was taken at the quarry first mentioned. The limestone in this quarry, like that in the railroad quarry, is weathered into furrows and ridges that are parallel to the bedding. The stone in both quarries ranges in color from reddish-brown to greenish-gray. It is extremely siliceous, as is evidenced by the analysis that follows below:

ANALYSIS (No. 10) OF GREENBRIER LIMESTONE, NEAR BARRELLVILLE.

Silica (SiO_2)	19.99
Alumina (Al_2O_3)	2.45
Iron oxide (Fe_2O_3)	1.07
Lime (CaO)	42.29
Magnesia (MgO)	.57
Ignition	33.77
Total	100.14

The second set of samples of Greenbrier limestone selected for analysis was obtained as stated on Stony Run. The point where these samples were taken is at Nos. 39-40 of the map a short way up the stream north of where the run crosses the road leading from Westernport to Dawson. The Greenbrier here is not of a sufficient workable thickness to have any commercial importance. Analysis (No. 40) gives the composition of a $7\frac{1}{2}$ -foot ledge of blue-gray limestone below the 8 feet represented in the sample on which analysis (No. 39) was made:

ANALYSES OF GREENBRIER LIMESTONE, WESTERNPORT.

	No. 39.	No. 40.
Silica (SiO_2)	13.86	2.94
Alumina (Al_2O_3)	4.58	1.09
Iron oxide (Fe_2O_3)	1.61	.68
Lime (CaO)	43.21	53.44
Magnesia (MgO)	1.50	.10
Ignition	34.87	42.15
Total	99.63	100.40

ALLEGANY COUNTY.
LIMESTONE.

No.	Name of limestone.	Nearest town.	Silica (SiO ₂).	Alumina (Al ₂ O ₃).	Iron (Fe ₂ O ₃).	Lime (CaO).	Magnesia (MgO).	Ignition.	Total.	CaCO ₃ .	Analyst.
1	Cayuga.	Corriganville.	26.57	3.96	1.73	34.95	1.96	29.66	98.83	62.3	M. R. Schmidt.
2	"	"	16.45	2.94	1.24	42.23	2.25	35.45	100.57	75.3	M. R. Schmidt.
3	Helderberg.	"	3.62	.72	.38	51.81	1.53	42.15	100.26	92.3	M. R. Schmidt.
4	"	"	10.29	1.65	.44	48.73	.72	38.65	100.48	86.7	M. R. Schmidt.
5	"	"	15.63	2.66	.81	42.63	2.32	36.12	100.17	76.0	M. R. Schmidt.
5½	"	"	8.00	.66	.38	50.24	.65	40.01	99.94	89.3	M. R. Schmidt.
6	Oriskany.	"	48.54	5.50	2.21	22.29	1.05	18.23	99.32*	39.7	M. R. Schmidt.
7	"	"	53.21	4.22	1.66	21.98	.55	18.09	99.71	39.2	M. R. Schmidt.
8	"	"	56.07	4.02	1.26	20.88	.46	16.98	99.17	37.2	M. R. Schmidt.
9	"	"	69.82	4.97	1.59	18.76	.10	10.38	100.62	24.6	M. R. Schmidt.
10	Greenbrier.	Barrellville.	19.99	2.45	1.07	42.29	.57	33.77	100.14	75.4	M. R. Schmidt.
11	"	"	5.24	1.98		47.33	3.56	41.12	99.26	84.4	T. M. Price.
12	Cayuga.	Cumberland.	28.72	12.28	5.22	25.54	1.10	21.13	95.52†	45.6	C. Richardson.
13	"	"	24.74	16.74	6.30*	23.41	4.10	18.99	102.68†	41.7	Q. A. Gillmore.
14	Helderberg.	"	12.27	12.88		41.14	0.41	32.54	99.24	73.4	T. M. Price.
14½	"	"	8.51	3.30		52.13	3.05	38.29	100.28	93.0	T. M. Price.
15	Oriskany.	"	57.49	4.40		15.05	5.16	17.46	99.56	26.8	
16	Helderberg.	Allegany Grove.	12.01	1.54	.75	47.06	1.05	37.69	100.10	83.8	M. R. Schmidt.
17	Cayuga.	Potomac.	26.43	8.18		30.32	6.12	28.74	99.79	53.9	T. M. Price.
18	"	"	17.60	5.66	3.01	35.44	4.77	32.74	99.22	63.3	M. R. Schmidt.
19	"	"	17.91	6.14		40.95	1.36	33.00	99.36	73.1	T. M. Price.
20	"	"	20.90	33.14		20.69	4.12	20.77	99.62	36.8	T. M. Price.
21	"	"	14.50	4.40		44.46	0.57	35.40	99.33	79.2	T. M. Price.
22	"	"	34.01	5.60		33.06	0.86	26.92	100.45	59.1	T. M. Price.
23	"	"	16.33	14.43		35.08	2.95	30.72	99.56	62.6	T. M. Price.

*FeO.

†Incomplete.

ALEGANY COUNTY—Continued.
LIMESTONE.

No.	Name of limestone.	Nearest town.	Silica (SiO ₂).	Alumina (Al ₂ O ₃).	Iron (Fe ₂ O ₃).	Lime (CaO).	Magnesia (MgO).	Ignition.	Total.	CaCO ₃ .	Analyst.
24	Helderberg.	Potomac.	.79	9.03		43.73	1.24	39.55	99.35	86.7	T. M. Price.
25	Cayuga.	"	7.30	1.85	.87	49.65	.88	39.59	100.14	88.3	M. R. Schmidt.
26	"	"	9.11	2.13	.99	47.76	.96	38.82	99.82	85.3	M. R. Schmidt.
27	"	"	11.25	2.39	.97	47.03	.88	37.55	100.09	83.7	M. R. Schmidt.
28	Helderberg.	Rawlins.	30.61	.62	.70	38.08	.81	29.94	100.76	67.9	Zies and Gill.
29	"	"	13.47	2.69	.95	43.11	3.37	37.21	100.80	76.9	Zies and Gill.
30	"	"	12.95	.47	.68	47.71	.90	37.53	100.24	85.1	Zies and Gill.
31	"	"	11.72	1.19	.75	46.54	2.34	33.07	100.61	83.0	Zies and Gill.
32	Cayuga.	Dawson.	3.69	1.27	.82	51.51	1.04	41.65	99.73	91.9	Zies and Gill.
33	"	"	3.82	.75	.53	51.06	1.56	41.36	99.13	91.1	Zies and Gill.
34	"	"	10.67	1.23	1.16	44.55	3.23	37.35	98.90	79.5	Zies and Gill.
35	"	"	9.17	.90	.72	49.36	1.60	39.03	100.83	88.1	Zies and Gill.
37	Helderberg.	Keyser, W. Va.	1.85	1.45		52.57	.63	42.00	98.50	93.5	W. Va. Geol. Survey Report, Vol. III, p. 341.
38	Oriskany. †	"	71.12	4.12	1.56	11.68	.35	9.59	98.42	20.8	M. R. Schmidt.
39	"	"	71.43	4.09	2.59	10.88	.78	9.14	98.91	19.4	M. R. Schmidt.
39½	Greenbrier.	Westernport.	13.86	4.53	1.61	43.21	1.50	34.87	99.63	76.8	M. R. Schmidt.
40	"	"	2.94	1.09	.63	53.44	.10	42.15	100.40	94.9	M. R. Schmidt.
41	"	"	5.11		3.56	49.88	1.62	29.85	99.92	88.8	T. M. Price.
42	"	"	3.65	8.44		48.01	.62	38.54	99.23	85.6	T. M. Price.
43	"	"	11.52	3.37		41.71	5.25	38.51	100.36	74.2	T. M. Price.

ARGILLACEOUS MATERIALS.

1	Romney.	Corriganville.	62.05	13.32	7.62	.99	.71	6.21	(§)	(§)	M. R. Schmidt.
			* Includes alkalies.		† Includes alkalies and SO ₃ .		‡ Calcareous sandstone.		§ Incomplete.		

Summary and Statistics for Allegany County.

Allegany is more of a mining than an agricultural county. Hence it is not surprising that it ranks fourth in the production of lime, which, as it will be recalled, is burned and used in Maryland mainly for agricultural purposes. In 1908 the lime product of this county was valued at \$8540 which was a little less than two-thirds the return brought for limestone quarried and sold for other purposes. The limestone sold for ballast, road-metal, concrete, etc., was valued at \$11,664. No cement was reported for this year. The total value for all limestone products was \$20,204. The names of the principal operators are listed below:

LIME AND LIMESTONE OPERATORS IN ALLEGANY COUNTY.

OPERATOR.	OFFICE.	QUARRY.
Cumberland Hydraulic Cement and Manufacturing Company	Cumberland	Cumberland.
Tresher, Charles F.	"	Winchester Bridge.
Gunning, J. B.	Cresaptown	Cresaptown.
Miller, C. A. L.	Cumberland	Cumberland.
Oss, Robert	Cresaptown	Cresaptown.

GARRETT COUNTY.

GEOGRAPHICAL LIMITS.

Garrett County includes within its limits that part of Maryland between Allegany County on the east and the State of West Virginia on the west. It lies almost wholly within the limits of the high and broad region of the Allegany Plateau.

GEOLOGY.

The rocks reaching the surface in Garrett County are all sedimentary in origin, and consist of shales and sandstones, the former predominating, which range in age from Devonian to Permian. Besides these is one limestone formation, the Greenbrier, and thin-bedded limestones in some of the Carboniferous formations. The latter are relatively unimportant, and are more valuable as guide members to the coal seams than they are for commercial uses.

The geological formations found in Garrett County are as follows:

TABLE OF GARRETT COUNTY FORMATIONS.

Cenozoic.		
Quaternary.		
Paleozoic.		
Permian (?)	.....	Dunkard.
Carboniferous..	{ Pennsylvanian or Coal Measures.....	{ Monongahela.
		{ Conemaugh.
		{ Allegheny.
		{ Pottsville.
	{ Mississippian	{ Mauch Chunk.
		{ Greenbrier
		{ Pocono.
Devonian	.....	{ Hampshire.
		{ Jennings.

These formations are folded into a series of gentle rolls which extend northeast and southwest. Within the limits of the county occur two gently arching anticlines, bringing lower Carboniferous and Devonian formations to the surface, and three gently depressed basins or synclines holding the Carboniferous formations.

Calcareous Materials.

Limestones occur at several horizons in the Carboniferous, but all are relatively insignificant and of no commercial importance except those of the Greenbrier. This formation may be divided into three members. The lowest is very siliceous, grading into the underlying Pocono sandstone, and is of little or no account. The middle members, composed of thin-bedded, sandy limestones and shales, is likewise of little value. This is, moreover, usually hidden or partially covered with wash and vegetation. The upper member, furnishing as it does the main source of lime of this region, is, however, of considerable value, even though it is a comparatively poor deposit. It is about 65 feet in thickness. The following measured section at Friendsville, which is west of the western anticline previously mentioned, gives the lithologic character of this member. Neither the top nor the bottom portions of this upper member are represented in the first of the sections. The second section, however, is fairly representative.

SECTION TWO MILES SOUTHEAST OF FRIENDSVILLE, GARRETT COUNTY.

	Feet.	Inches.
1. Massive limestone	2	
2. Shaly limestone	3	
3. Massive limestone	5	
4. Shale		8
5. Limestone		9
6. Shale		7
7. Massive blue limestone.....	12	
	—	—
Total	24	

SECTION ON BALTIMORE AND OHIO R. R., EAST OF CRABTREE, GARRETT COUNTY.*

	Feet.
1. Gray sandstone (Mauch Chunk).....	
2. Red shale	5
3. Red shale and limestone.....	16
4. Red limestone with corals.....	5
5. Concealed	10
6. Gray shaly and sandy limestone with occasional fossils.	15
7. Massive reddish limestone.....	15
	—
Total	66

* Martin, G. C. Geology of Garrett Co., p. 97.

The Greenbrier formation occurs at the surface in three entirely separate areas in Garrett County. One of these areas is so complicated in its boundaries that in describing the surface distribution it may be considered as made up of four connected areas, making a total of six Greenbrier areas in the county. The most easterly of these areas is situated parallel to and about $\frac{1}{2}$ mile west of the crest of Savage and Backbone mountains. It enters the county from Pennsylvania $\frac{1}{2}$ mile west of the northeast corner of the county, and extends in a southwesterly direction to the West Virginia line, 1 mile north of Potomac Stone. This belt is about 45 miles long, and from $\frac{1}{4}$ to $\frac{1}{2}$ mile wide. It occupies a valley between the Pottsville (Savage Mountain) and the Pocono (Little Savage Mountain) ridges. Along the northern end of Backbone Mountain the line of outcrop is, for a large part of the way, up on the mountain-side, but farther south it occupies a series of minor valleys like those along Savage Mountain.

The second area extends along the eastern side of Meadow Mountain in the valleys of Red Run and Meadow Mountain Run, as far as the confluence of the latter with Deep Creek near Thayerville. Thence it extends in the same southwesterly direction, in a similar series of valleys between Hoop Pole Ridge and the ridge of Pottsville rocks to the west of it, to the West Virginia line at a point about 7 miles southwest of Oakland. This belt is about 37 miles long, and from $\frac{1}{3}$ to $\frac{1}{2}$ of a mile wide.

The third area extends from a point near Thayerville, on the one last described, down the valley of Deep Creek to the mouth of Marsh Run, thence up the valley of Marsh Run to McHenry, thence in a westerly direction for about 1 mile, where it bifurcates. One prong extends down the valley of Hoyes Run for about 1 mile, where it dips under the overlying formation. The other extends in a northwesterly direction through a valley to Sang Run. From here it extends up and down the valley of the Youghiogheny River to points $1\frac{1}{2}$ miles north and $2\frac{1}{2}$ miles south of Sang Run, where it dips under the overlying formation.

The fourth area extends from a point on the one last described at McHenry, in a north-northeasterly direction in the valley parallel to and about $\frac{1}{2}$ mile west of Negro Mountain as far as and across the Pennsylvania line. This belt is about 15 miles long and $\frac{1}{3}$ of a mile wide.

The fifth area extends from a point on the third one, about 1 mile east of Sang Run, in a northerly and northeasterly direction until it crosses the Pennsylvania line at Oakton. It occupies a sinuous line of valleys parallel to and about $\frac{1}{2}$ mile east of the crest of Winding Ridge. This belt is about 13 miles long and $\frac{1}{3}$ of a mile wide.

The sixth area enters the county from West Virginia near Cranesville, and extends south along the valley occupied by Pine Swamp and Muddy Creek as far as Browning Mill, and thence up the valley lying west of Snaggy Mountain for about 4 miles. Here it extends across the line into West Virginia.

Argillaceous Materials.

The argillaceous materials of Garrett are widely distributed, forming, as they do, most of the surface area of the county. The shales of

Devonian age have already been described in a previous section. Shales of Carboniferous age would also be available in inexhaustible quantity for Portland cement manufacture. There is no prospect, however, of either these or the Devonian shales being used for this purpose, since, so far as known, there are no occurrences of limestone in Garrett County where the limestone is of suitable quality and quantity to enter with the shales into a Portland cement mixture.

GARRETT COUNTY—LIMESTONES.

No.	Nearest Town.	Quarry.	Silica (SiO ₂).	Alumina (Al ₂ O ₃).	Iron (Fe ₂ O ₃).	Lime (CaO).	Magnesia (MgO).	Ignition.	Total.	CaCO ₃ .	Analyst.
1	Piney Grove.	Findley.	4.47	2.70	48.57	3.04	41.50	100.28	86.73	T. M. Price.	
2	Floyds.		8.57	2.38	53.24	.41	35.94	100.54	88.73	T. M. Price.	
3	Thayerville.		20.95	41.10	20.92	.43	16.91	100.81	87.35	T. M. Price.	
4		Orfutt.	17.00	2.74	35.91	7.50	44.16	99.61	64.12	T. M. Price.	
5	Friendsville.	Gerringer and Neflehart.	13.65	5.44	44.33	.57	35.46	99.46	79.16	T. M. Price.	
6	Crellin.	Orfutt.	13.46	12.48	40.85	.55	32.67	100.01	72.92	T. M. Price.	

SUMMARY AND STATISTICS FOR GARRETT COUNTY.

The Greenbrier limestone is used extensively for making lime for local consumption. The lime that is obtained from calcining the Greenbrier is used chiefly for agricultural purposes. Also this formation is worked to a limited extent as a road-making material. The statistics of the amount and value of the production used for various purposes are, however, not available. This is due mainly to the fact that the operations are on a small scale, are more or less intermittent, and so most of the operators fail to make their reports to the State Geological Survey. In the absence, however, of detailed data it will suffice to say that the total output and its value is known to be small.

THE COASTAL PLAIN MARLS.

The Coastal Plain marls are more likely to be used for burning to agricultural lime than as an ingredient in Portland cement, and probably will never be used to any great extent for either. Nowhere in Maryland are they found both in sufficient thickness and of suitable chem-

ical composition to be used in the manufacture of Portland cement. It is obvious that both these requirements—namely quality and quantity of materials—must be met if the marls of this section are to form the basis of the industry just mentioned. Nor would they be employed for making lime except for the absence where they occur of any other calcareous material of better quality. Usually it is cheaper to buy lime in some other section and ship it to its destination in the Coastal Plain, paying the additional cost of transportation, rather than attempt to manufacture lime from the local raw material.

The land in the Coastal Plain, however, is sadly in need of lime, but its cost under present conditions is high, and because of this the shell marls are occasionally calcined to obtain lime for use for local agricultural purposes. With the introduction of hydrating plants at most of the Maryland kilns, especially those of Baltimore County, it will be possible to manufacture a product that can be shipped safely by water and sold in the Coastal Plain region of the State at a reasonable price. At present the excessive cost is due largely to the high tariff charged on caustic lime because of the danger of fire always involved in shipping it by boat. Water transportation is the chief, if not the only convenient means of reaching a large portion of the Coastal Plain, and so if lime is to be shipped at a moderate rate and sold at a reasonable cost, it must be hydrated to eliminate from the lime its most dangerous and objectionable feature; the manufacturer of hydrated lime may thus develop with the product—i. e., hydrate lime—a large, profitable, and almost entirely new market.

The writers have examined a large number of occurrences of Eocene and Miocene marls, and of the total number only a very few had sufficient economic importance to require sampling for analysis. One of the best of the deposits seen is found near Marlboro, the county seat of Prince George's, as a ledge in the Aquia formation. As Marlboro is a station, both on the Chesapeake Beach Railroad and on the Popes Creek Branch of the Philadelphia, Wilmington and Baltimore Railroad, the station on the former being called Upper Marlboro, the deposit is well situated for bringing in fuel and sending out the finished product.

Unfortunately, the quality of the best exposures seen, represented by the accompanying analysis, could be used only for burning lime for local consumption. Analysis follows below:

ANALYSIS OF INDURATED SHELL-MARL FROM THE AQUIA FORMATION, MARLBORO,
PRINCE GEORGE'S COUNTY.*

Silica (SiO_2)	19.70
Alumina (Al_2O_3)	1.53
Iron oxide (Fe_2O_3)	4.63
Lime (CaO)	39.96
Magnesia (MgO)	1.11
Ignition	33.08
Total	100.01

* East of road north from Marlboro. 500 feet S. of fork to Marlboro station. Thickness of bed about 8 feet.

Another exposure of shell marl, where the marl is considerably thicker than near Marlboro, is that at Mackall's Wharf, St. Leonard's Creek, at its juncture with the Patuxent. The total thickness of the marl is not exposed at this locality, but its estimated thickness is about 12 feet, of which 9 feet is exposed. The sample taken here analyzed as follows:

SAMPLE OF MIOCENE MARL, MACKALL'S WHARF, CALVERT COUNTY.

Silica (SiO_2)	52.54
Alumina (Al_2O_3)	1.32
Iron oxide (Fe_2O_3)	.54
Lime (CaO)	25.21
Magnesia (MgO)	.85
Ignition	19.99
Total	100.45

Shell marl of a similar sort is found exposed also at Jones Wharf, which, in a straight line a few degrees south of west, is about 4 miles west of Mackall's Wharf, but on the opposite side of the river from the latter. The marl bed here is exposed for $2\frac{1}{2}$ to $3\frac{1}{2}$ feet above water, and, as at Mackall's, consists of shells more or less tightly cemented together by an arenaceous-calcareous cement. Because of its high content of silica it is not suitable for use for lime burning, though in the pulverized

state it would doubtless be used as a fertilizing material with satisfactory results. At both these places mentioned the shell marl occurs as a member of the Choptank formation, which, stratigraphically, is the middle one of the three formations in Maryland, comprising the Chesapeake group of the Miocene.

Above the Choptank formation shell marl occurs also in the St. Mary's formation. Usually it is not of a workable thickness, and nowhere has it any economic importance. The following is the analysis of a sample taken about midway between Chancellor and Windmill, points on the east side of St. Mary's River, the latter, i. e., Windmill Point, being the point where St. Inigoes Creek empties into the river. The bed here is very thin, not exceeding 2 feet in thickness.

SAMPLE OF MARL FROM THE ST. MARY'S FORMATION TAKEN BETWEEN WINDMILL AND CHANCELLOR POINTS, ST. MARY'S COUNTY.

Silica (SiO_2)	35.12
Alumina (Al_2O_3)	2.28
Iron oxide (Fe_2O_3)	3.22
Lime (CaO)	29.14
Magnesia (MgO)	3.89
Ignition	26.31
Total	99.96

From the above analysis and from the thickness—less than 2 feet—of the bed from which this sample was taken, it is evident that it has no economic value whatever.

Many other localities besides those mentioned were examined in the hope that material would be found suitable in quality and quantity for the manufacture of Portland cement or for the manufacture of lime. The quest, however, was in vain. Some of the marl deposits may be used for making lime for local uses, but neither in the Miocene nor Eocene, nor in any of the formations of the Coastal Plain, are there known occurrences which are adapted for use in the manufacture of cement, because where the beds are satisfactory as regards chemical composition or quality there exist an insufficient quantity of material to justify the erection of a plant which would base its operations on its use.

The following analysis was made on a sample of the green marl occurring at Chesapeake Beach, taken about $\frac{1}{2}$ mile south of the pier. It contains a little over 1 per cent. of lime, and is submitted here to show the chemical composition of this material, which in the past has been somewhat extensively employed as a fertilizer because of its content of phosphorus.

SAMPLE OF MIOCENE MARL FROM THE CALVERT FORMATION, CHESAPEAKE BEACH,
CALVERT COUNTY.

Silica (SiO_2)	89.58
Alumina (Al_2O_3)	2.66
Iron oxide (Fe_2O_3)	1.88
Lime (CaO)	1.06
Magnesia (MgO)	.52
Phosphorus (P_2O_5)	.77
Ignition	3.63
Total	100.10

THE LIME AND CEMENT INDUSTRY IN MARYLAND.

INTRODUCTORY.

The materials in Maryland suitable for making lime and natural and Portland cements are widely distributed. The lime industry is already an important one. The total product in 1907 was valued at \$344,316. A number of plants have also been built to manufacture natural cement, but their output has fallen off in recent years owing to the fact that Portland cement is rapidly replacing their product. One plant for the manufacture of Portland cement is in operation, and another, comprising facilities for the manufacture of both Portland cement and hydrated lime, is in process of erection.

A considerable proportion of the limestone quarried in the State is used for building purposes, road-making, ballast, or concrete. Limestone suitable for blast-furnace flux and for use in the open-hearth process of steel-making is also known to occur. The statistics on the production of limestone gathered by this Survey do not show how much has been quarried and sold exclusively for flux, and apparently the production for this purpose is small. Most of the limestone used for

flux at Sparrows Point is shipped from the vicinity of Martinsburg, West Virginia.

The total production of limestone for other purposes than the manufacture of lime and cement is given below. The figures show that the production has increased from an output valued at \$13,801 in 1896, to an output valued at \$142,825 in 1907. Another important fact brought out is the steady increase shown in the past eight years in the consumption of crushed limestone for ballast and for concrete work, the latter being one of the indications of the increased use, during the same period of time, of cements in construction work of all sorts.

Crushed stone for ballast and concrete is sold both by the ton and by the perch, the latter equalling about 2500 pounds. The prices quoted for broken and crushed limestone in Maryland ranges between 70 cents to \$1.25 per perch, and from 60 cents to \$1.00 per ton.

VALUE OF ANNUAL PRODUCTION OF LIMESTONE,† 1896-1908 IN MARYLAND.

	Building.	Flagging, curbing and paving.	Crushed— Road ballast and concrete.	Sold for flux and lime.	Miscellaneous— Rubble and riprap.	Total.
1896	*	*	*	*	*	\$13,801
1897	*	*	*	*	*	16,924
1898	\$10,768	*	\$155,714	\$3,446	\$276	170,204
1899	8,896	*	7,292	869	647	17,703
1900	11,385	*	14,343	7,593	2,169	35,490
1901	14,138	\$1,796	59,663	4,707	420	74,724
1902	16,953	1,575	95,966	9,097	3,022	126,613
1903	8,361	6,748	48,464	1,419	80	65,732
1904	12,836	1,036	111,147	2,466	902	128,387
1905	42,766	246	100,641	699	5,050	149,402
1906	8,393	779	160,109	*	765	170,046
1907	2,100	1,937	137,288	*	1,450	142,825
1908	13,105	150	114,405	210	721	128,591

† Exclusive of lime and cement.

* Statistics incomplete in detail.

THE LIME INDUSTRY.

The lime-making industry is at present by far the most important of the industries dependent on the use of Maryland limestone. The lime produced in 1905 reached the highest value, so far as Maryland is concerned, in the history of the industry, amounting to \$360,247, or

over 2.4 times the value of the limestone reported for use for other purposes.

Lime production and the value of the total product, with the exception of comparatively small fluctuations, has been steadily increasing during the past 10 years. This may be seen by reference to the table below. The larger part of the product was used in liming land and most of the rest in construction work.

TABLE OF VALUE OF LIME PRODUCED ANNUALLY IN MARYLAND.

1896	\$250,477
1897	182,441
1898	263,449
1899	217,522
1900	281,717
1901	307,657
1902	326,417
1903	320,494
1904	309,079
1905	360,247
1906	350,460
1907	344,316
1908	332,455

The greater part of the lime made in Maryland is obtained from burning limestone in the old-fashioned vertical, mixed-feed, continuous kiln, though some of the kilns employed are constructed along more modern lines. Better styles of kilns not only would effect a great saving in the cost of production, but would, at the same time, result in a much better commercial product. Continuous kilns, built of stone, are universally used in the larger plants. These, however, are being gradually supplanted, with the growth of the industry, by steel-clad kilns lined on the interior with the variety of fire-brick best adapted for that purpose. In the regions removed from transportation routes and where the demand is small, and lime is made only to supply the local demand, the more primitive intermittent kiln may, however, still be found in use.

Some of the larger plants in the State sell lime by the ton, but in most cases it is sold by the bushel—of 2150.42 cubic inches capacity.

The bushel, however, is estimated in practice by weight rather than by cubic inches. This varies from 70 to 90 pounds. The great majority of plants, however, report the bushel as weighing 80 pounds, and figure on 25 bushels of lime to the ton.

The price of lime in Maryland, as elsewhere, varies, of course, with the quality of the product. The lower grades of lime sell for from $7\frac{1}{2}$ to $9\frac{1}{2}$ cents, and the best grades that are manufactured near Baltimore at about 16 cents to the bushel. The range in price varies, therefore, from $7\frac{1}{2}$ to 16 cents per bushel f. o. b. at the point of shipment. The average price per bushel during 1907 was about 12 cents. The higher prices were obtained in the Texas-Cockeysville district, and the lower prices for the inferior grades of lime at standard plants, and for high-grade lime manufactured at points less accessible to the larger markets.

The fuels used in the lime kilns of Maryland consist chiefly of anthracite and semi-bituminous coal, the latter coming from the western section of the State. Charcoal and wood are also employed for burning, but to a more limited extent. Anthracite coal being on the whole lower in ash and volatile matter and having a higher calorific value than any one of the other fuels mentioned is, on this account, generally preferred. It is bought and burned in the form of pea-coal or anthracite siftings, 1 ton of which will burn about 125 bushels or 5 tons of lime, or, in other words, 1 ton of anthracite will decarbonate about 10 tons of limestone.

Roughly, the calorific value of 1 ton of anthracite is equal to $1\frac{1}{8}$ tons of coke, and 1 ton of coke is equal to about $1\frac{1}{3}$ tons of bituminous coal. Hence, 1 ton of bituminous coal is equivalent to about $\frac{2}{3}$ of a ton of anthracite coal, and will, therefore, calcine nearly 7 tons of limestone. But these figures stating the relative calorific value and efficiency of the three fuels mentioned involve several obvious errors. They were compiled from the reports received from Maryland limestone operators who, in reporting the fuel used, gave the sort of fuel used (but not its analysis), the cost, amount used, and also the output of the plant. Before reaching an accurate comparison of the anthracite, bituminous

coal and coke one must know, besides the lime output and gross cost of the fuel, something of the quality of the fuel and the character of the limestone used. The figures given above, therefore, are only approximate, but they show nevertheless that in general the value and efficiency of anthracite, coke, and bituminous coal for calcination of limestone is in the order named, and that as a mixed-feed fuel in the continuous kiln in this State they are generally preferred by the operators in the order just mentioned.

The outlay for fuel in the manufacture of lime amounts to from 4 to 6 cents a bushel. The fuel item thus reaches from 70 to 80 per cent. of the total cost, which ranges from $5\frac{1}{2}$ to $7\frac{1}{2}$ cents per bushel. With lime ranging in price from 10 to 16 cents for the better grades, and averaging about 12 cents per bushel, the lime operator, with good management, has a very fair margin of profit.

Lime is sold either as "lean" or "fat" lime, depending on the content of lime (CaO) and magnesia (MgO). Both varieties are made in Maryland. The "fat" or caustic limes are manufactured from burning limestone containing less than 10 per cent. of magnesia, while the "lean" or magnesian limes are made from limestones containing more than 10 per cent. of magnesia. The former or the high calcium, called also caustic limes, with the addition of water, slake more rapidly than the "lean" or magnesian limes, and also set more slowly. The fact that the magnesian limes in slaking emit less heat for a unit of time than the "caustic" limes, and moreover set more rapidly, cause them to be preferred in some lines of work to the "caustic" limes. In general, however, the "fat" or caustic lime is the variety most in demand.

THE PORTLAND AND NATURAL CEMENTS INDUSTRY.

Maryland possesses abundant materials for the manufacture of Portland cement, but, unfortunately, the competition with Portland cements, from which the Maryland natural cement industry has had to suffer, has come from neighboring states which, with the exception perhaps of Pennsylvania, are no better supplied with raw materials.

The cities of Baltimore and Washington together consume annually

about 1,200,000 barrels of Portland cement. The demands of other though smaller markets, which Portland cement plants located in Maryland might also control, because of their proximity, and the transportation facilities that this State affords, amounts to almost as much, making a total of about 2,500,000 barrels. Yet there is but a single plant built in Maryland and a second in course of construction, whereas there should be several, aggregating a daily capacity of 10,000 to 12,000 barrels. This backwardness in cement manufacture is due largely to a lack of information as to the State's resources in this respect, and also because only within the past year or so has the subject of the Portland cement resources of Maryland been at all systematically studied.

The natural cement industry throughout the United States, with the exception of the years 1897, 1898, and 1902 has shown each year a decrease in production compared with the year preceding. The industry in Maryland has been no exception. The production of natural and slag cements, which is given below, reached in 1896 a total of 250,000 barrels, valued at \$115,000, but in the next 10 years the output steadily decreased until in 1906 the production amounted to 66,350 barrels, or a little more than one-fourth of the output reported for the first year of the decade, 1896-1906.

At the close of 1907 not one of the four Maryland natural cement plants or the one slag cement plant that had been constructed at Sparrows Point was in operation. The effect of closing down of these plants will, however, only be temporary. Their place in the industrial activity of the State will be more than occupied by the Portland cement industry; for the cessation of operation of the last of the natural cement plants in the fall of 1907 was followed by the construction of the first Portland cement plant to be built in Maryland, which began manufacturing in 1908. At the present time a second large Portland cement plant is being erected, while a hydrated-lime plant proposes to place its product on the market before this report is distributed.

It is safe to predict that other Portland cement plants will also be built, for Maryland is plentifully supplied with material which is well adapted for use in this industry.

TABLE OF PRODUCTION OF NATURAL AND SLAG CEMENTS PRODUCED IN MARYLAND.

	Barrels.	Average price.	Value.
1896	250,000	\$0.46	\$115,000
1897	200,000	.52	104,000
1898	307,475	.44	136,489
1899	372,000	.42	154,800
1900	343,070	.41	140,028
1901	358,329	.54	180,665
1902	423,200	.38	161,180
1903	279,957	.53	148,619
1904	70,000	.51	36,250
1905	61,324	.54	33,494
1906	66,350	.49	32,675
1907* .....	.....	.....	.....
1908 .....	.....	.....	.....

* To give the figures for 1907 and 1908 would disclose the product of individual operators since three or more plants have not reported production during the year.

The cement plant constructed at Sparrows Point, the statistics of whose output are included in the foregoing table, is the only one in Maryland located east of the Blue Ridge. It was built in 1898, and was the second plant established in this country for the manufacture of slag cement.

Most, if not all, of the ores used in the furnaces at Sparrows Point come from foreign sources, the greater part of the tonnage being mined and shipped from Cuba. When the slag-cement plant was in operation these were fluxed chiefly with limestone, marble, and oyster shells, and the resulting slag was granulated and used in the manufacture of slag cement. The capacity of the works is 500 barrels a day. The cement manufactured by the Maryland Cement Company is reported as a non-staining puzzolan with an average specific gravity of 2.90+. The future successful operation of this mill, which is now closed, appears doubtful.

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LIFE.

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